IOWA GEOLOGICAL SURVEY
IOWA CITY, IOWA
H. GARLAND HERSHEY, Director and State Geologist

REPORT OF INVESTIGATIONS 1

STRATIGRAPHY OF THE OSAGE SERIES IN SOUTHEASTERN IOWA

by

STANLEY E. HARRIS, JR.
MARY C. PARKER

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ILLUSTRATIONS

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ABSTRACT

The Osage Series in southeastern Iowa is composed primarily of cherty carbonate rocks. Thin shale beds appear in the middle of the series and increase upward in number and thickness. The lithologic character and thickness of the series are relatively uniform throughout the area. This gives no suggestion of major changes in environment of deposition or tectonics either laterally or vertically.

It is convenient to consider the area in two parts, the southeastern district and the western district. Subsurface sections in the southeastern district are readily matched to the classic surface exposures of the Burlington Limestone, Keokuk Limestone, and Warsaw Formation near the Mississippi River. The lithologies of the three formations are so similar that small changes, and especially dolomitization toward the west, make tracing of boundaries difficult.

The Burlington Limestone is divided in the southeast into three members that are named and described in this report. The Dolbee Creek Member at the base and the Cedar Fork Member at the top are mainly recrystallized crinoidal bioclastic limestone. The Haight Creek Member in the middle is very cherty and contains much dolomite even in the east. Glauconite at the base of the Haight Creek and disseminated in the Cedar Fork is a persistent horizon marker. Haight Creek and Cedar Fork are found throughout the area; Dolbee Creek is restricted to the southeastern district.

The Keokuk Limestone is characterized by mottled gray bioclastics and chert in the southeast, and brownish-black cherts with white spicules and argillaceous dolomite in the west. The carbonate is argillaceous and the formation contains shale beds throughout the area. No sharp boundary marks the contact with the overlying Warsaw Formation. The latter consists of grayer dolomite beds and much more shale than the Keokuk; chalcedonic chert and crystalline quartz are generally abundant.

The Warsaw Formation is included in the Osage Series because of its gradational relationship to the underlying Keokuk Limestone and because of the unconformity above it.

Graphic well sections and photomicrographs illustrate the lithologic nature of each unit. Cross sections, thickness maps, and a lithofacies map of the Keokuk-Warsaw Formations depict the changes and regional variations. Structural features are shown by a map using as a datum the base of the Haight Creek Member of the Burlington Limestone.

The original sediments were marine limestone and shale deposited under stable shelf conditions. The limestones consisted mainly of disarticulated crinoid skeletons which were spread evenly over the sea floor but appear not to have been carried far by waves or currents. There is little evidence of bar accumulation. The occurrence of thicker shale sections peripheral to anticlines suggests that these structures may have been active at the time of deposition. Both dolomite and chert are probably diagenetic.

Iowa was beyond the reach of terrigenous deposits from the Appalachian tectonic belt. Any land in the direction of the Canadian Shield was certainly very low, and the seas extended widely to northwest and southwest.

INTRODUCTION

Purpose and Scope

This report presents a description of the lithology, distribution, thickness, and relationships of the Osage rocks of the Mississippian System, as they occur in subsurface in the southeastern quarter of Iowa. The location of the area of study is shown in figure 1. Maps showing thickness, structure, and lithofacies are also presented.

The intent is: 1) to relate subsurface well records to surface formation usage; 2) to standardize the classification of various workers; 3) to correlate the formations of the Osage Series in central Iowa with the type formations of southeastern Iowa; 4) to make a preliminary interpretation of the conditions of origin; and 5) to distinguish the later diagenetic changes.

Procedure

This report is based primarily on the examination of well cuttings with binocular microscope and throughout the report reference is made to the well sample sets by Iowa Geological Survey file number e.g., (W-4000). The records of over a thousand wells were used in the completion of this report. The locations of the

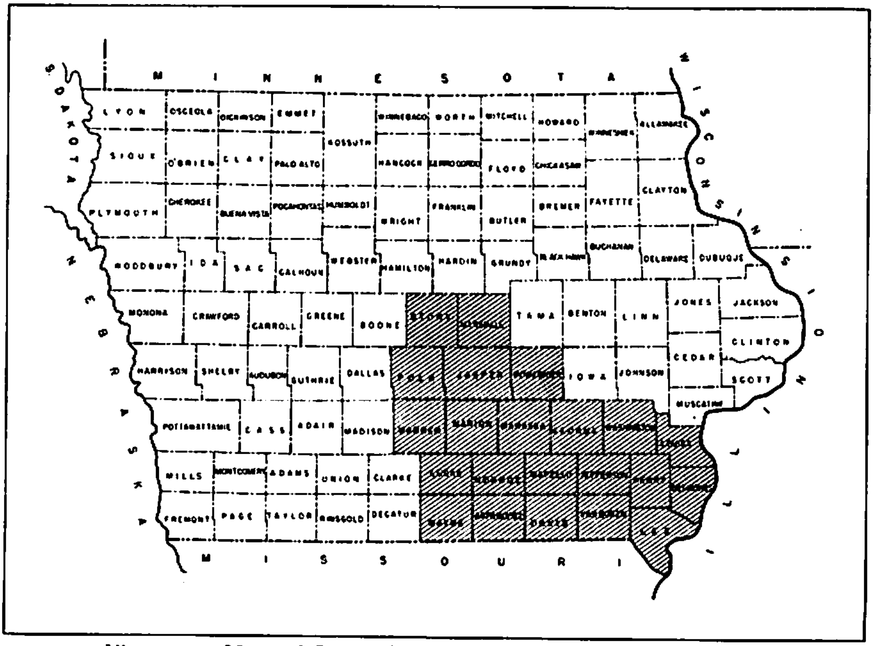


Figure 1. Map of Iowa showing location of area of study.

wells to which specific reference is made are listed in the appendix. The samples are mostly from holes drilled by the cable-tool method by many water-well drillers whose excellent cooperation has made possible the subsurface stratigraphic work of the Iowa Survey. A few cores and sample sets from rotary-drilled holes were also available. In general the well sections were readily correlated with surface sections. Several quarries and natural exposures were measured and hand specimens were compared to well cuttings. Examination of well cuttings proceeded according to geographic location, progressing from southeastern Iowa toward the northwest with the purpose of tracing units or recognizing changes from well to well. Several sets of insoluble residues were examined, and residues of selected intervals were made whenever it seemed desirable.

The criteria for correlation are mostly lithologic. No faunal studies were made, although presence or absence of fossil or skeletal remains and the gross assemblage are usable means of correlation. Descriptive terminology conforms basically to the usage of the Iowa Geological Survey and standard references of stratigraphy and sedimentary petrology. Color usage follows "The Rock Color Chart" (National Research Council 1948) based on the Munsell system. Description of limestones has been influenced by Folk's (1959) classification, although his rather complex terminology is not used. The graphic logs prepared as a part of this investigation are in the files of the Iowa Geological Survey. The logs of many workers have been drawn upon especially in the construction of the maps accompanying this report. Explanation of the symbols used in the graphic illustrations of surface exposures and the percentage logs of well cuttings is shown in figure 2.

The maps, prepared mainly by Parker, are based on well records available to the spring of 1961. Control is of irregular density. In the southeastern counties a great deal of detail is possible and certain structural trends are defined. In the southwestern counties well records are few and scattered and structural trends can not be defined with certainty.

Previous Work and Classification

The Mississippian rocks of Iowa and adjacent states have been studied repeatedly since the work of Owen (1852) and Hall (1857). Reviews of these investigations may be found in the

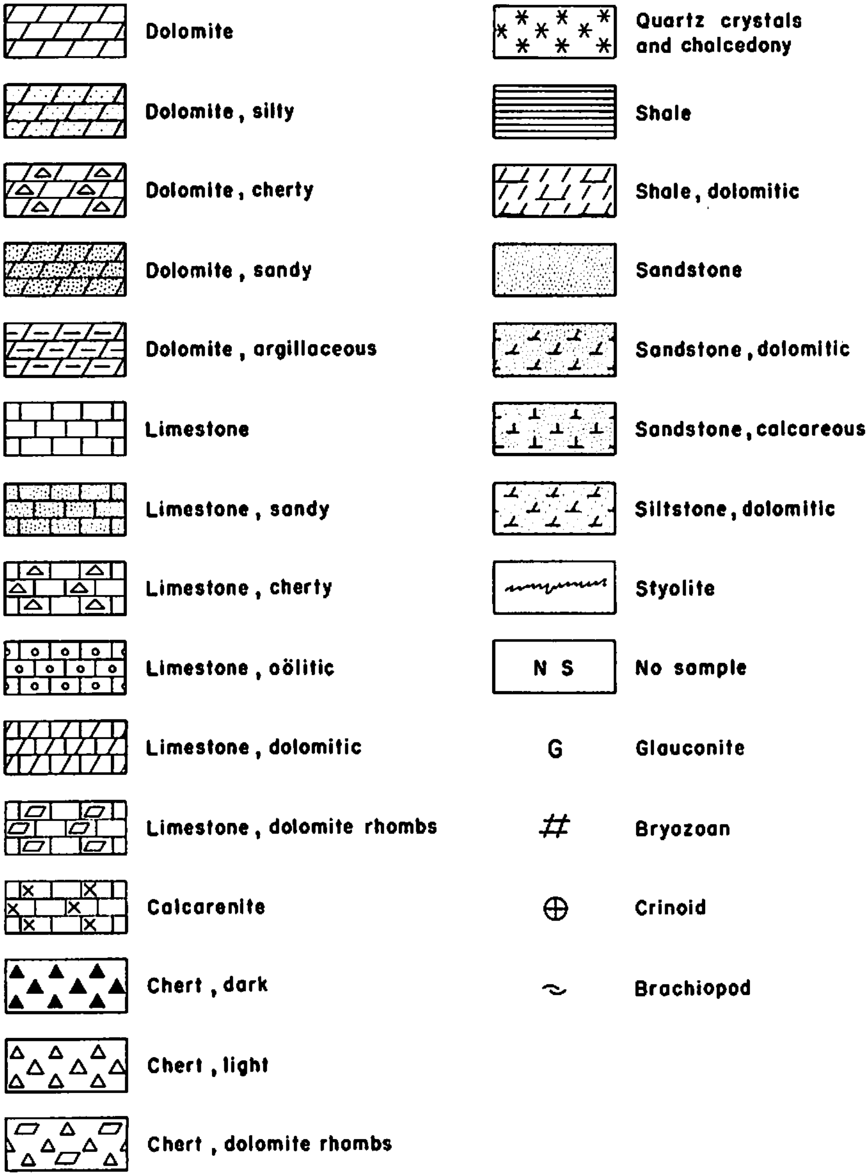


Figure 2. Explanation of symbols used in percentage logs and graphic illustrations.

works of Van Tuyl (1922), Moore (1935), Wilmarth (1938), and Weller and Sutton (1940).

There has been much disagreement over the placement of the boundary between the Osage and Meramec Series, and various authors have placed this boundary both at the base of and at the top of the Warsaw Formation. Van Tuyl (1922), J. M. Weller (1934), Weller and Sutton (1940), and Weller and others (1948), all assign the Warsaw Formation to the Meramec Series on the basis of faunal assemblage and lithologic affinities. Warsaw and Spergen (Salem) are conformable in southwestern Illinois and in the St. Louis area, whereas in southeastern Iowa there appears to be an unconformity between these formations. Stuart Weller (1914), Moore (1935), and Laudon (1931, 1937, 1949) have taken the view that both faunally and lithologically the Warsaw is more closely related to the Keokuk than to the Spergen-St. Louis.

The results of this investigation emphasize the gradational relationship of the Warsaw and the Keokuk. On the other hand the Spergen marks the initiation of quartz sand grains characteristic of the Meramec sediments.

The Osage Series, as used in this report, is composed of the Burlington Limestone, Keokuk Limestone, and Warsaw Formation. The nomenclature and usage of previous authors and the usage of this report are summarized in figure 3.

In Illinois and Missouri, the Burlington Limestone is underlain by the Fern Glen Formation which is also Osage in age. This formation has not been found in Iowa. In southeastern Iowa

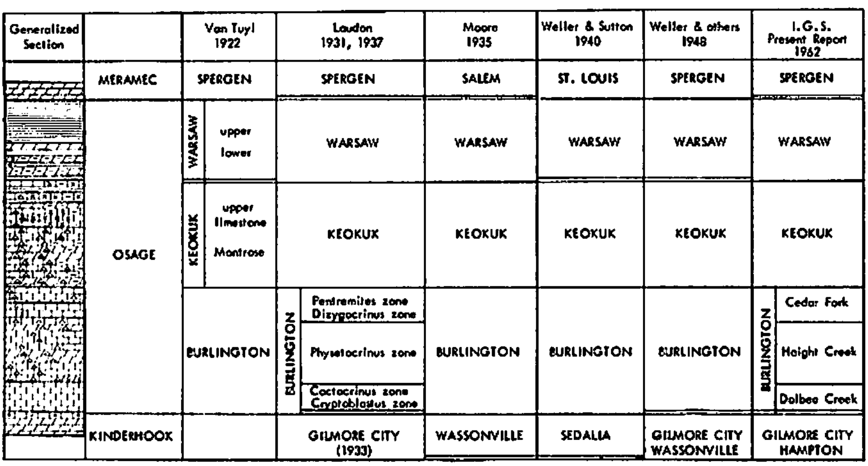


Figure 3. Nomenclature and usage of Osage Series in southeastern Iowa

the Burlington Limestone marks the base of the Osage Series and is underlain by the Hampton Formation. In central Iowa, the Burlington is underlain by the Gilmore City Limestone which may be of Osage age. The stratigraphic relationships of the Gilmore City Limestone are questionable and are currently undergoing investigation by several geologists in Iowa. For the purposes of this report, the Burlington is considered to be the base of the Osage in central Iowa also.

ACKNOWLEDGEMENTS

The study was initiated by Harris while a member of the Iowa Geological Survey staff in the mid-1940's in preparation for a doctoral dissertation (Harris, 1947). The work was directed by H. Garland Hershey, State Geologist and Director of the Iowa Geological Survey. Since that time examination of hundreds of additional well sections by many Survey staff members has confirmed the boundaries and divisions suggested. These well records have been used extensively by the authors in preparing the present report. Parker has been mainly responsible for evaluation of the earlier work and for construction of new maps.

The writers express special thanks to Charles N. Brown, Assistant State Geologist for encouragement in carrying through the restudy, to Walter L. Steinhilber, U. S. Geological Survey District Geologist, for his criticism and helpful suggestions, and to the members of the present staff whose discussion, interest, and criticism has made possible the completion of this report. F. H. Dorheim and R. B. Campbell joined the authors in establishing type sections for the members of the Burlington Limestone.

STRATIGRAPHY

The Osage Series in southeastern Iowa is composed dominantly of cherty carbonate rocks interstratified with minor amounts of fossiliferous shale. The carbonate strata are now crystalline, but many beds were originally biogenic. Thin shale beds first appear in the middle of the series, and increase upward in number and thickness. Quartz sandstone occurs only locally at the base of the Burlington Limestone and has been noted in parts of Washington, Keokuk, and Louisa Counties.

The outcrop area of the Osage Series and the thickness of the series are shown in plate 1. Recent subsurface data have modified the Osage boundaries of the Geologic Map of Iowa (Tester, 1937).

Two stratigraphic cross-sections are shown in figures 4 and 5. The relative uniformity of the Burlington members in the southeastern district and the extent of the lithologic variations from southeast to northwest are shown in figure 4, and from southwest to northeast in figure 5. The thinning of the Osage Series on the southwestern flank of the anticline near Ames-Roland and the contact of the Burlington with successively younger horizons of the Kinderhook Series from southeastern Iowa northwestward are shown in figure 4. The inter-relationship of the Warsaw-Keokuk carbonates and shales is demonstrated on both cross-sections.

Description of Formations

Burlington Limestone

General Statement

The Burlington Limestone was named by James Hall (1857) to replace the term "encrinital group of Burlington" which had been used by Owen (1852). The Burlington is the lowermost formation of the Osage Series in southeastern Iowa and overlies rocks of Kinderhook age; it is overlain by the Keokuk Limestone. The contact between the Burlington and Keokuk Formations is not sharp and has been placed at various horizons by earlier workers. Transitions beds between the formations were called "Montrose cherts" by Keyes (1893) who considered them to be part of the Burlington. Van Tuyl (1922), largely on the basis of faunal relationships, placed these beds in the Keokuk Limestone. The Iowa Geological Survey continues to accept Van Tuyl's in-

Figure 4. Northwest - southeast stratigraphic cross section of Osage Series

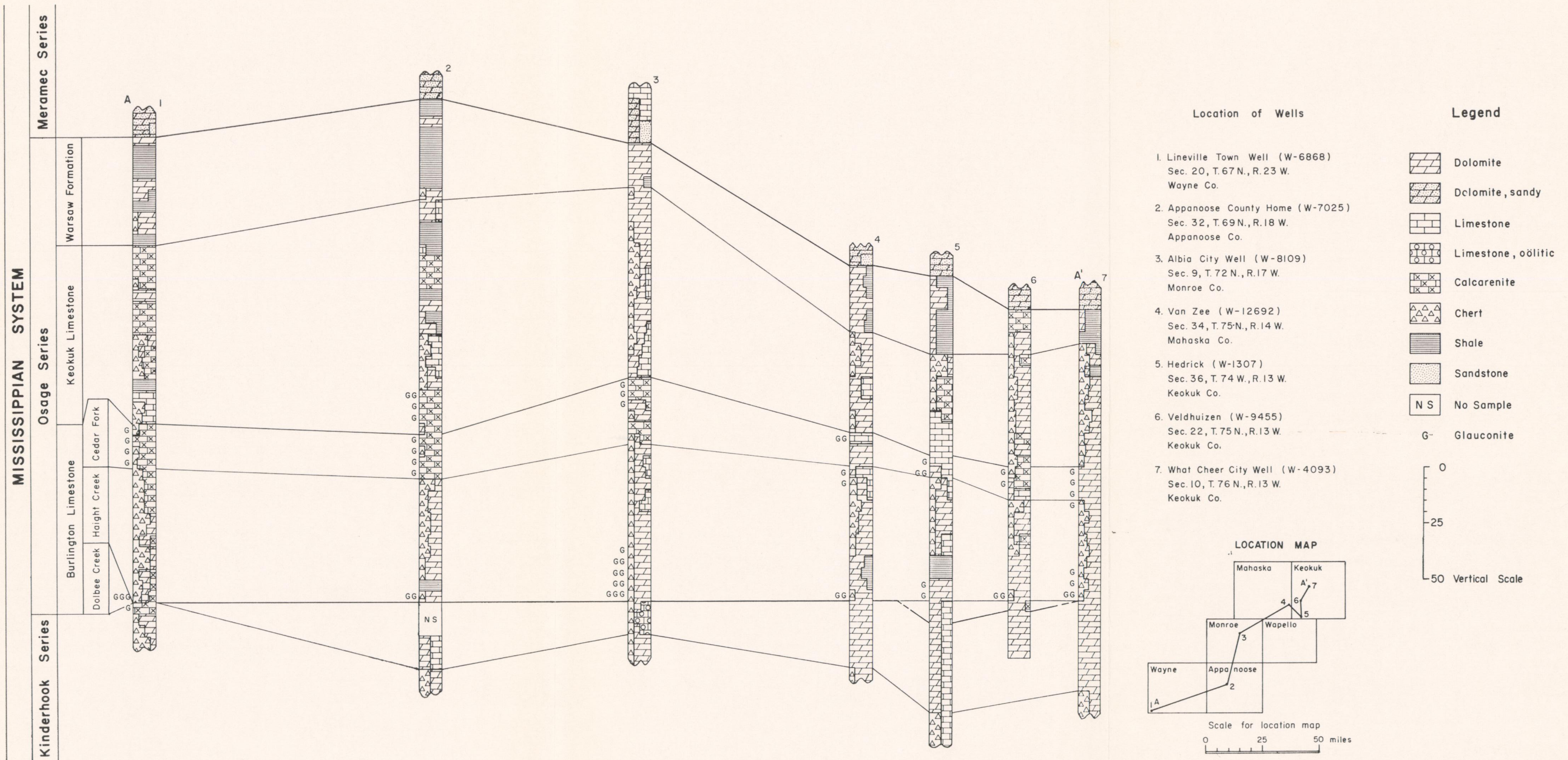


Figure 5. Southwest - northeast stratigraphic cross section of Osage Series

terpretation which was concurred in by Laudon (1937) in his report on the Burlington Limestone.

Distribution and Thickness

The type area of the Burlington Limestone is at Burlington, Des Moines County, Iowa. The formation has a broad outcrop area. Exposures are relatively common in much of Des Moines and Lee Counties and parts of Van Buren, Henry, Louisa, and Washington Counties. Quarries expose the Burlington in Keokuk, Jasper, Poweshiek, and Marshall Counties, but natural exposures of the formation are not known there. Subsurface data show that it is well developed beneath younger strata throughout southeastern Iowa as shown on the Burlington structural and thickness maps, plates 2 and 3.

The thickness of the Burlington Limestone ranges from 40 to 80 feet, with the thicker section in the south and west as shown in plate 3. Rocks of the same age are distributed throughout much of central United States and are represented in the Rocky Mountain area.

Surface Characteristics

The Burlington Limestone in outcrop has been described by Van Tuyl (1922) and Laudon (1929, 1937). The latter (1937) subdivides the formation into faunal zones which correspond to the lithologic members described herein.

As a result of subsurface studies Harris (1947) divided the Burlington Limestone into three units. These have correlated so well with surface exposures that member names are here proposed and type sections designated and described from Des Moines County. The members in ascending order are, Dolbee Creek, Haight Creek, and Cedar Fork. In general, the Dolbee Creek Member (Laudon's *Cactocrinus* zone in the type area, but including his underlying zones where the member is thick) is relatively pure crinoidal limestone with a small amount of chert; the Haight Creek Member (Laudon's *Physetocrinus* zone) is highly cherty and contains dolomite as well as limestone beds; and the Cedar Fork Member (Laudon's *Dizygocrinus* and *Pentremites* zones) is relatively pure crystalline limestone. The *Dizygocrinus* zone commonly contains abundant glauconite which gives the limestone a green color, and the *Pentremites* zone is cherty.

The Burlington Limestone is resistant to erosion and forms a high northeast facing escarpment along the northern margin of

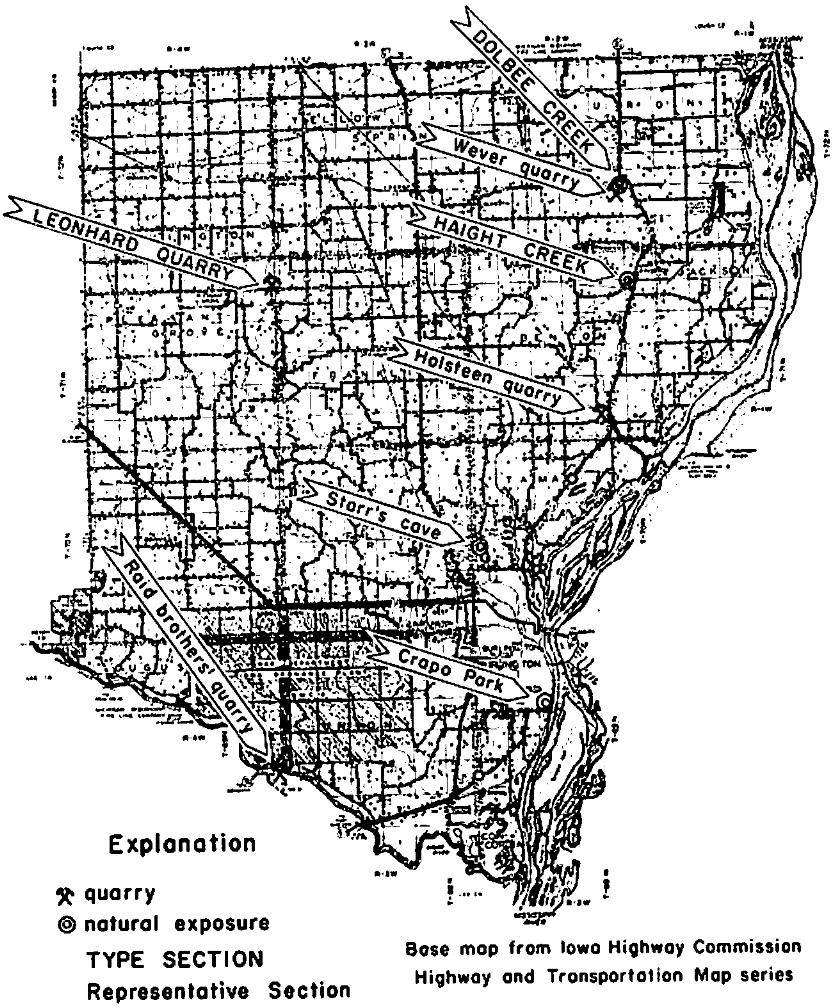
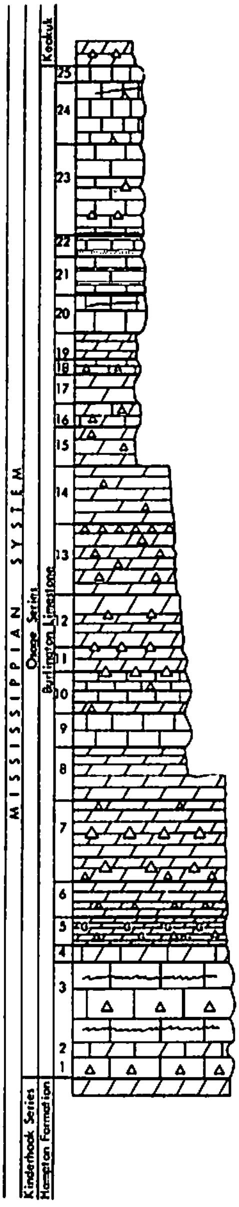


Figure 6. Map of Des Moines County, Iowa showing locations of Type and representative sections of the Burlington Limestone



Keokuk Limestone
Dolomite, dusky-yellow (5 Y 6/3), finely crystalline calcareous, massive beds of white, mottled chert

Cedar Fork Member

25. Limestone, very coarsely crystalline, glauconitic, fish-tooth horizon 1.0'
24. Limestone, light-gray, coarsely crystalline, crinoid fragments, recrystallized calcite in sparry matrix, stylolitic 4.0'
23. Limestone, light-gray, coarsely crystalline, Spirifer grimesi abundant, lenses and nodules of white, tripolitic to porcellaneous chert, mottled light-gray (N 9 to N 7); light bluish-green (5 B 7/1), slightly dolomitic, blocky shale at base 7.0'
22. Limestone, greenish-gray (5 G 6/1), coarsely crystalline; soft flecks of glauconite (5 G 5/2) 1.0'
21. Limestone as below, numerous shale partings 2.0'
20. Limestone, light-gray (N 7), coarsely crystalline, calcite recrystallized from crinoids; disseminated glauconite (5 G 5/2) Dyzigocrinus 3.0'

Haight Creek Member

19. Dolomite, grayish-orange (10 YR 7/4), finely crystalline, calcite 2.0'
18. Limestone, yellowish-gray (5 Y 8/1), medium-crystalline, dolomitic 1.0'
17. Dolomite, grayish-orange, finely crystalline, massive, friable 2.0'
16. Limestone and dolomite, irregularly mottled 1.5'
15. Dolomite, moderate yellowish-brown (10 YR 5/4), finely crystalline, calcareous, with siliceous fossil fragments 3.0'
14. Dolomite, brown, finely crystalline, thick-bedded 4.0'
13. Dolomite, grayish orange-pink (5 YR 7/2), finely crystalline; mottled gray (5 YR 5/1 and 5B 7/1) chert, banded parallel to margins, prominent cross-bedding on north face 5.0'
12. Dolomite, brown, finely crystalline, dense, light- to dark-gray mottled chert, chalcedonic to porcellaneous, irregularly bedded to nodular 3.5'
11. Dolomite, light olive-gray (5 Y 6/1), finely crystalline 1.5'
10. Limestone as below, coarsely crystalline, crinoidal 3.0'
9. Limestone, yellowish-gray (5 Y 8/1) interbedded with brown dolomite layers 3.0'
8. Dolomite grading into dolomitic limestone, light-gray; finely crystalline, dense, massive 4.0'
7. Dolomite as above with light- to medium-gray, porcellaneous chert, some fossiliferous; chalcedony-lined vugs; dolomite speckled with white siliceous fossil fragments 5.5'
6. Dolomite, brown, finely crystalline, thin-bedded, white siliceous fossil fragments, porous; with thin stringers of mottled, fossiliferous chert 2.5'
5. Dolomite, brownish-gray, finely crystalline, dense; laminae of greenish-black, rounded polished glauconite, nodules of chert 2.0'
4. Dolomitic limestone, brownish-gray, finely to coarsely crystalline, glauconitic 1.0'

Dolbee Creek Member

3. Limestone, very light-gray (N 8), coarsely crystalline, crinoidal, massive, styolitic; lenses of white tripolitic chert 5.5'
2. Limestone, dolomitic, finely crystalline 1.0'
1. Limestone, pale-orange (10 YR 8/3), coarsely crystalline 1.5'

Wassonville Member
Dolomite, light-gray (N 7), finely crystalline

Figure 7. Burlington Limestone section exposed in Leonhard Quarry SE cor. sec. 1, T. 71N., R. 4W., Des Moines County, Iowa. Key to symbols given in figure 2.

the outcrop area in Des Moines County. The high bluffs along the Mississippi Valley wall in the vicinity of the city of Burlington are capped by Burlington rocks. Tributary valleys such as Flint Creek, Yellow Spring Creek, Dolbee Creek and their branches commonly have steep valley walls cliffed by the resistant Dolbee Creek and Cedar Fork Members. Where the entire formation is present, as at Starr's Cave and the mouth of Dolbee Creek, there are two cliffs separated by a steep talus-covered slope. In many places the massive crystalline limestone members form great overhangs beneath which "shelter bluff caves" are formed at the horizons of the weaker underlying beds. Such shelter bluffs are especially prominent at Crapo Park in Burlington and at Starr's Cave in the dolomites of the Haight Creek Member and the Wassonville Formation. Northwestward along the strike the scarp is buried beneath glacial till. Locations of the type sections of the members and representative natural and quarry exposures are shown on the map of Des Moines County, figure 6. The complete stratigraphic section of Burlington Limestone and contacts with the underlying Wassonville dolomite and overlying Keokuk Limestone is very well exposed at the present time in the J. T. Leonhard quarry located in the SE cor. sec. 1, T. 71N., R.4W., Des Moines County. This would make an ideal type section for the entire Burlington Limestone, however, most of the section is below the level of Cedar Fork Creek and eventually may be covered by water. The section is shown in figure 7. *Dolbee Creek Member.*—The type section of the Dolbee Creek Member is exposed along Dolbee Creek near the Dolbee cemetery, in the SE ¼ SE¼ sec. 23, T. 72N., R. 2W., Des Moines County, Iowa (fig. 8).

Other typical exposures of the Dolbee Creek Member can be seen in the abandoned Holsteen quarry along a tributary to Yellow Spring Creek in the NW cor. sec. 35, T. 71N., R. 2W.; in the Flint River bluff near Starr's Cave in the NW¼ NW¼ sec. 19, T. 70N., R. 2W.; in the bluffs above the Mississippi River at Crapo Park, Burlington; and in the Leonhard quarry (fig. 7).

The Dolbee Creek Member in surface exposures commonly forms massive ledges or over-hanging cliffs. The dominant lithology is very dense, coarsely crystalline, crinoidal limestone. It contains scattered chert nodules and is sparingly dolomitized. *Spirifer grimesi* and fragments of bryozoans are also prevalent

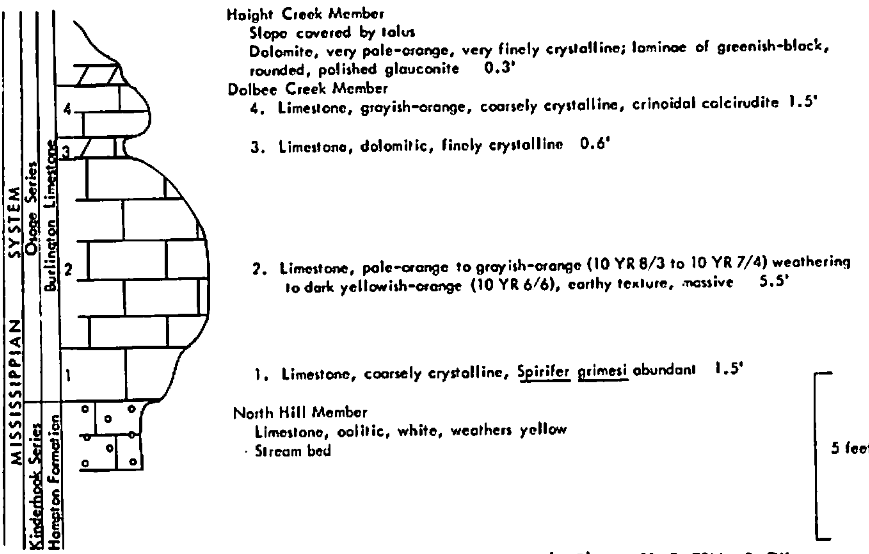
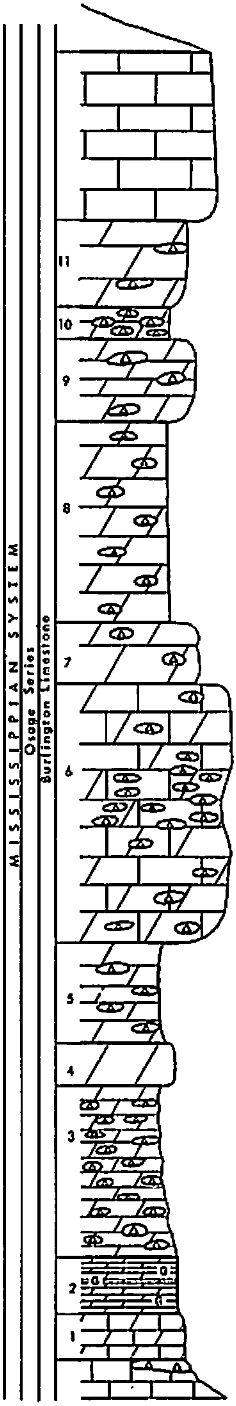


Figure 8. Type section of Dolbee Creek Member, Burlington Limestone SE¼ SE¼ sec. 23, T. 72N., R. 2W., Des Moines County, Iowa. Key to symbols given in figure 2.

in this member. It rests unconformably on rocks which are more susceptible to weathering. At the type locality, the Dolbee Creek Member is underlain by the oolitic limestone of the North Hill Member of the Hampton Formation. At Crapo Park, Starr's Cave, and Leonhard quarry, the Dolbee Creek is underlain by the brownish-red dolomites of the Wassonville Member of the Hampton. *Chonetes* are prevalent in the Wassonville. The top of the Dolbee Creek is a coarsely crystalline, crinoidal calcirudite conformably overlain by a nonresistant dolomite containing one or more massive chert beds. Within a few feet of the contact in the base of the Haight Creek Member there occurs a distinctive zone of thin-bedded dolomite with laminae of greenish-black rounded glauconite grains.

Haight Creek Member.—The type section of the Haight Creek Member is exposed in a bluff on the north bank of Haight Creek in the NW cor. sec. 12, T. 71N., R. 2W., Des Moines County (fig. 9). The bluff is approximately 100 yards west of the bridge over Haight Creek on Iowa Highway 99, approximately half a mile south of the community of Kingston.

Other typical exposures can be seen at the type section of the Dolbee Creek, where the Haight Creek forms a steep talus slope,



Cedar Fork Member
Covered

Limestone, very pale-orange to light-gray, coarsely crystalline, very crinoidal, disseminated glauconite as soft flecks 6.0'

Haight Creek Member

11. Dolomite, grayish-orange (10 YR 7/4), fine- to medium- crystalline and grayish-tan, smooth, fossiliferous chert 3.0'

10. Dolomite, yellowish-brown, medium-crystalline, slightly porous, earthy, gray to white, mottled, fossiliferous chert 1.0'

9. Dolomite, yellowish-tan (10 YR 5/4), fine- to medium- crystalline, porous, hard, massive; scattered nodules of grayish-tan, dolomitic chert, calcite-lined vugs 3.0'

8. Dolomite, yellowish-brown, finely crystalline, earthy, non-resistant, many nodules of brown dolomitic chert 7.0'

7. Dolomite, brown, finely crystalline, porous, hard, dense, contains molds of crinoid fragments; scattered nodules and lenses of brown dolomoldic chert 2.0'

6. Limestone, yellowish-gray (5 Y 8/1), finely to medium-crystalline, dolomitic, very crinoidal; light gray, mottled, fossiliferous, smooth, opaque chert occurs in scattered nodules and lenses concentrated near the middle of the unit, forms resistant ledge that stands out prominently from the bluff 9.0'

5. Dolomite, tan, finely crystalline, earthy, non-resistant, light gray, rough, opaque chert occurs in very irregular nodules along bedding planes, fractures easily 3.5'

4. Dolomite, grayish-brown, hard, dense, stands out as a resistant ledge 1.5'

3. Dolomite, light brownish-gray to light-brown, finely crystalline, appears earthy; light- to medium-gray chert occurs in beds and nodules, some fossiliferous 6.0'

2. Dolomite, brownish-gray, finely crystalline, dense, laminae of greenish-black, rounded, polished glauconite grains 2.0'

1. Limestone, coarsely crystalline, crinoidal, glauconitic, dolomitic, thick-bedded; light-gray, mottled with white, smooth, opaque chert 1.0'

Dolbee Creek Member
Limestone, light yellowish-gray (5 Y 7/2) coarsely crystalline, crinoidal
Stream bed.

Figure 9. Type section of Haight Creek Member, Burlington Limestone NW cor. sec. 12, T. 71N., R. 2W., Des Moines County, Iowa. Key to symbols given in figure 2.

and in the adjacent Wever quarry in the NW cor. sec. 25, T. 72N., R. 2W., where all but the lower 5 feet can be seen. In the overhanging cliffs of the Flint River bluff near Starr's Cave the complete section is exposed but is inaccessible for detailed study. The upper portion of the member can be seen in the Raid Brothers' quarry at South Augusta in the SE¼ NW¼ sec. 25, T. 69N., R. 4W., Lee County; the lower portion can be seen in the abandoned Holsteen quarry and the entire section in the Leonhard quarry, both in Des Moines County (fig. 6).

The Haight Creek Member in surface exposures is commonly reduced to steep talus-covered slopes. The dolomites tend to disintegrate and the chert layers are highly fractured. A weather-resistant rock ledge, 3 to 5 feet high occurs at the horizon of crinoidal limestone and massive chert, generally found in the middle of the member. The Haight Creek is marked by numerous chert layers and dominance of dolomite over limestone. The chert occurs as irregular beds and nodular masses. When observed on the bedding plane these are seen to have a lattice-like pattern. The chert is characteristically offwhite to light gray and mottled with white to light yellowish-brown crinoidal fragments. At Leonhard quarry much of the chert is mottled gray or brown and has banding parallel to the margins of the nodules. The dolomites are brownish gray, finely crystalline and friable. Dense, coarsely crystalline, crinoidal limestone beds similar to those in the Dolbee Creek and Cedar Fork Members occur near the top and in the middle of the Haight Creek. They are somewhat finer in texture and are not glauconitic.

Cross bedding occurs in some localities and is particularly outstanding at Leonhard Quarry where interbedded chert layers have a uniform dip of about 15 degrees in bed 13.

Interlaminated glauconite and dolomite occupy a zone from 6 inches to 2 feet or more in thickness at the base of this unit. The glauconite grains are polished, well rounded, and greenish black (5 G 2/1) in color. It was deposited as a sand. This glauconite zone at the base of the Haight Creek is the most important horizon marker in the entire Osage Series, because it is as outstanding in well cuttings as it is in surface exposures.

The top of the Haight Creek is marked by a grayish-orange, finely crystalline dolomite with calcite cement. It is conformably overlain by resistant, coarsely crystalline, crinoidal limestone of the Cedar Fork Member.

Cedar Fork Member.—The type section of the Cedar Fork Member is exposed in the Leonhard quarry at an elevation which would be above the natural water table (fig. 7). The quarry is located near the east bank of Cedar Fork Creek.

Other typical exposures of the Cedar Fork Member can be seen along Cedar Fork Creek in sections 1 and 12, T. 71N., R. 4W., Des Moines County; at the type area of Dolbee Creek along Dolbee Creek and in adjacent quarries; and in the Raid Brothers' quarry at South Augusta.

The Cedar Fork Member like the Dolbee Creek, in surface exposures forms massive cliffs or overhangs. Its dominant lithology is coarsely to very coarsely crystalline, crinoidal limestone. Scattered glauconite is present throughout the Cedar Fork. A concentration which gives the rock a greenish color occurs in a zone two to four feet thick in the middle of the member. The glauconite occurs as disseminated grayish-green (5 G 5/2 to 5/4) flecks which are not rounded nor oriented in layers as they are at the base of the Haight Creek. Nodules and lenses of white, porcellaneous, and fossiliferous chert occur in the upper portion of the member. *Spirifer grimesi* and *Dizygocrinus* are abundant.

The top of the member is marked by a horizon containing numerous fish teeth, although evidence of these are rarely preserved in well cuttings. The enclosing limestone is very coarsely crystalline, crinoidal, and contains disseminated glauconite grains. The overlying Keokuk is composed of alternating dolomite and crinoidal limestone beds, which are very cherty and browner than those of the Cedar Fork Member.

Subsurface Characteristics in Southeastern District

The subsurface character of the Burlington Limestone is best considered in two areas—the southeastern and the western districts of the study area. In the region of the outcrop the lithologic character of the Burlington in subsurface is comparable to that in surface exposures, and the members of the Burlington Limestone are readily recognizable. These are well shown by the sample logs in figures 10 and 11. Northwestward the amount of dolomite gradually increases and both carbonates and cherts become darker in color. Marker beds and certain lithologic peculiarities (to be described) persist, allowing continuous recognition of the formation throughout the area covered by this report.

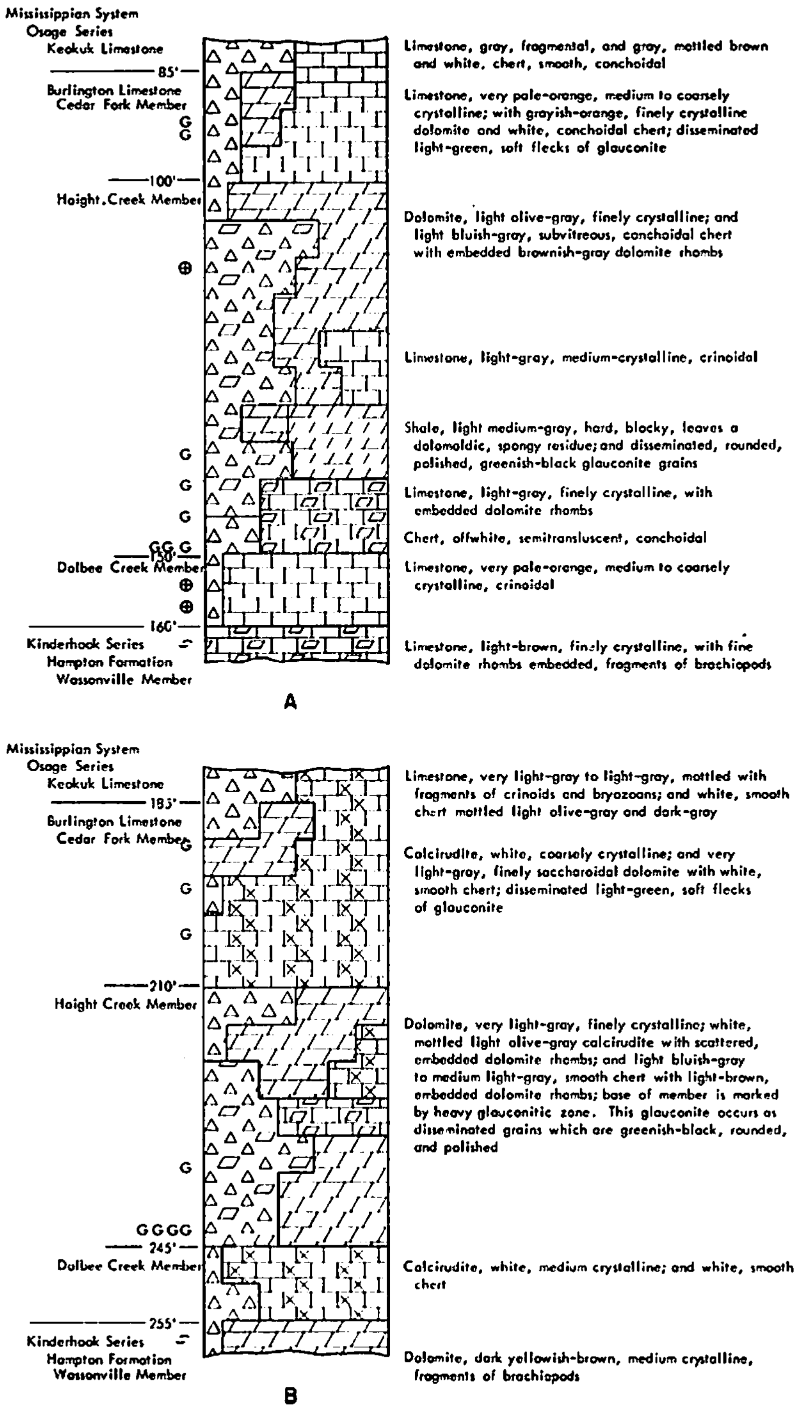
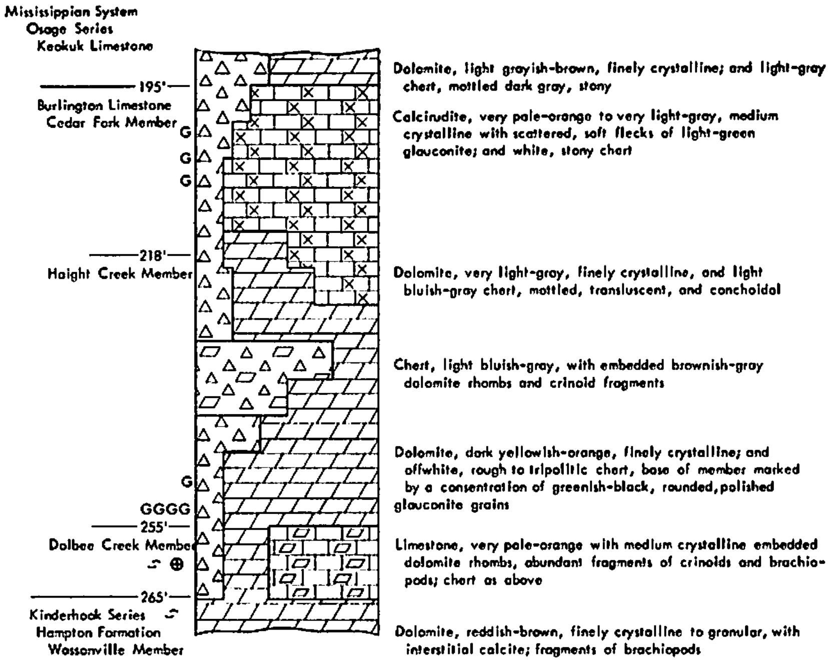


Figure 10. Percentage logs of well cuttings from Burlington Limestone at A. Keokuk Country Club, Lee County (W-0789), B. J. C. Foecke, Lee County (W-8167). Key to symbols given in figure 2.



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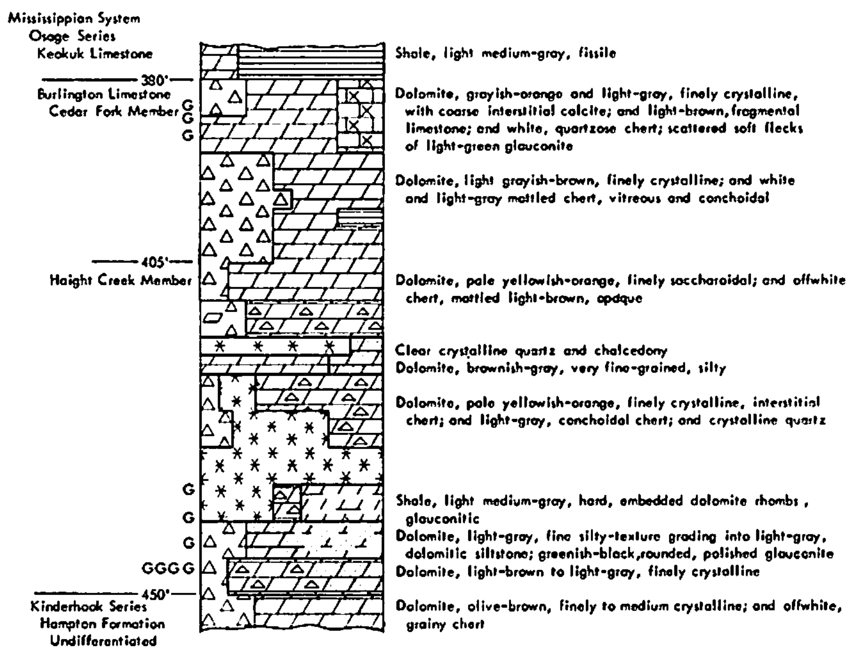


B

Figure 11. Percentage logs of well cuttings from Burlington Limestone at A. Iowa Ordnance Plant well 4 Des Moines County (W-1431), B. Wright Ringham, Story County (W-2164). Key to symbols given in figure 2.

Dolbee Creek Member.—Well cuttings of the Dolbee Creek Member are composed mainly of limestone with minor amounts of chert and glauconite. The limestone, in which crinoid fragments are abundant, is dominantly very pale orange (10 YR 8/2) to offwhite, coarsely to very coarsely crystalline (pl. 4, fig. 5). A small percentage of chert accompanies the limestone. This chert is generally white, opaque, conchoidal, and has a stony luster, but some of the chert may be dull and rough. The Dolbee Creek characteristically contains a small amount of light-green (5 G 6/3) glauconite. Disseminated dolomite crystals occur in the limestone in some localities as at the Iowa Ordinance Plant, Des Moines County (W-1414, fig. 11 A).

This unit is thickest in the south near Keokuk, Lee County, where it measures 17 feet in the Aikens well (W-1282, fig. 4). From that area northward and westward it decreases in thickness. Near Burlington, Des Moines County (W-1431), and Wayland, Henry County (W-1332), the unit is about 10 feet thick, and southeast of Crawfordsville, Washington County (W-1568), it is only 2 feet thick. In the vicinity of Ainsworth, Washington, and Wellman, all in Washington County, the Dolbee Creek is absent. The distribution is shown in plate 3.

In Washington, Keokuk, and Louisa Counties a basal sandstone or conglomerate occurs at the base of the Burlington Limestone. It rests on the Wassonville dolomite. An exposure of conglomerate composed of angular and rounded chert pebbles and quartz sand occurs 4 miles south of Riverside, Washington County, in the NW¼ SE¼ sec. 31, T. 77N., R. 6W. It rests on reddish-brown dolomite of the Wassonville and appears to represent a basal Burlington deposit. The relationship of the conglomerate to the Burlington Limestone is not observable at this exposure, although the Burlington is present 200 yards away. At the type locality of the Wassonville a well-sorted, friable sandstone occurs at the contact between the Burlington Limestone and the Wassonville dolomite. It is composed principally of fine- to medium-sized quartz grains which have secondarily enlarged crystal faces. Although most grains are colorless, some are pink and a few are dark brown or black. Small pebble-size balls occur with the sandstone.

Subsurface occurrences of a sandstone similar to that at Wassonville have been observed in samples from wells at:

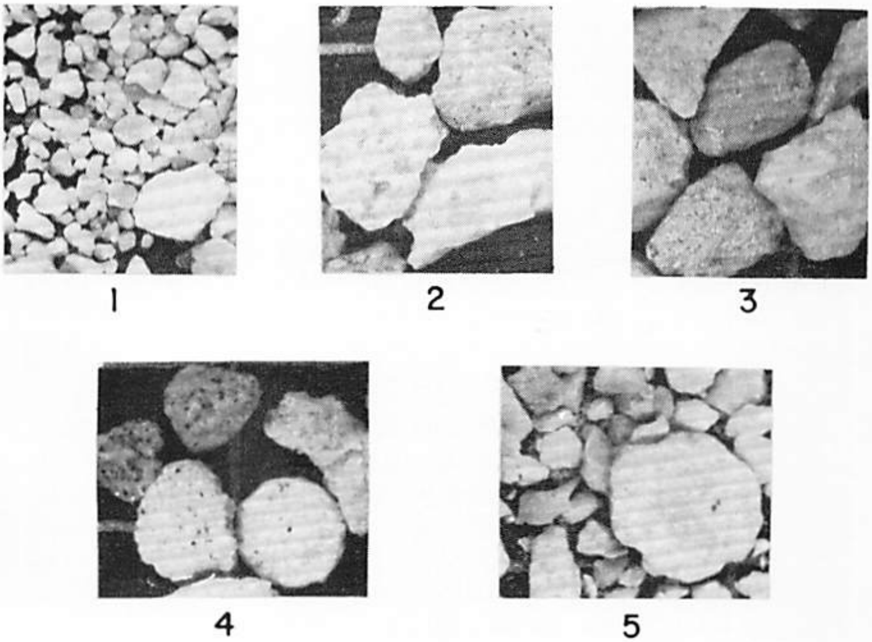


Plate 4. Photomicrographs of representative well cuttings of the Burlington Limestone X-7.

1. Cedar Fork Member (W-7981, 245' -250'): limestone (lower right) offwhite, coarsely crystalline; chert, white, opaque, stony luster.
2. Haight Creek Member (W-8167, 210' -215') near top of member: chert, offwhite, smooth, porcellaneous luster; limestone, offwhite, coarsely crystalline.
3. Haight Creek Member (W-8167, 235' -240') near base of member: dolomite (the darker fragments), finely crystalline, scattered dark grains of glauconite; chert (lower right) shows chalcedonic banding and mottling as well as fossil fragments.
4. Haight Creek Member (W-8167, 240' -245') base of member: rounded, polished, dark greenish-black glauconite pellets in the darker fine-textured dolomite and lighter coarsely-crystalline limestone.
5. Dolbee Creek Member (W-8176, 245' -250'): limestone coarsely crystalline, containing crinoid fragments; chert, white, smooth, opaque.

Name	*Town*	*County*
Wellman city No. 2 (W-2238)	Wellman	Washington
Washington city test No. 4 (W-0686)	Washington	Washington
Ainsworth city No. 2 (W-1868)	Ainsworth	Washington
Keota city (W-0551)	Keota	Keokuk
What Cheer city test (W-0822)	What Cheer	Keokuk
Clarence Jennings (W-2360)	Columbus Jct.	Louisa
Cotter School (W-3874)	Cotter	Louisa

The sandstone varies in texture from very fine to medium-grained, and is composed of quartz grains with well-developed crystal faces as a result of secondary growth. Yellowish-gray, unctuous clay accompanies the sandstone in most of these wells. The bed appears to be conglomeratic in the Keota well as it contains much weathered chert and brown clay along with sand.

Haight Creek Member.—The Haight Creek Member in subsurface is dominated by a high percentage of chert; as much as 50 percent in some localities. Generally both limestone and dolomite accompany the chert. The chert is offwhite, opaque, generally has a conchoidal fracture, and a stony luster. A peculiar and distinctive characteristic of the chert is the presence of grayish-pink rhombohedral dolomite crystals enclosed in the chert matrix (pl. 4, fig. 3). These crystals are commonly replaced by chalcedony. Some of the chert contains microscopic drusy quartz masses. The limestone is similar to that in the Dolbee Creek: white to very pale orange, fine to medium crystalline, crinoidal fragments with a clear calcite or siliceous cement (pl. 4, fig. 2). The limestone commonly grades into dolomite, as at Richland, Keokuk County (W-2387) and Pilot Grove, Lee County (W-1385). The accompanying dolomite, also siliceous, is pale orange (10 YR 7/2 to 10 YR 8/4), fine to medium crystalline, and has a brilliant luster. A small amount of glauconite is generally scattered through this unit.

The base of the Haight Creek in most well sections as in surface exposures, is marked by a glauconitic dolomite (figs. 10 and 11). The dolomite is darker and has a greater residue of argillaceous and siliceous material than most of the dolomites of the Haight Creek and has a silt-sized to medium-crystalline texture. The glauconite is typically greenish black (5 G 2/1), has a high luster, and a smooth rounded surface (pl. 4, fig. 4). This horizon has been used as the datum for the structure map of southeastern Iowa (pl. 2), because it is recognizable over the entire area. Additional detail is included in the section devoted to the western district.

The Haight Creek Member has a rather uniform thickness in the southeastern district ranging from 40 to 50 feet.

Cedar Fork Member.—The Cedar Fork Member in subsurface is composed mainly of carbonates with minor amounts of chert and glauconite. The carbonate of the Cedar Fork is dominantly an offwhite to very pale-orange limestone with a medium to coarsely crystalline texture; subordinate amounts of light olive-gray, finely crystalline dolomite are present (pl. 4, fig. 1). The rock is composed largely of crinoid fragments and hence might be termed a criquina (Tester, 1941), which is a biocalcirudite. The limestone is commonly very glauconitic, especially in the middle portion, and as a consequence may have a greenish color. The glauconite is generally soft and dark yellowish green (10 GY 4/4). Greenish-black, rounded, and polished grains similar to those at the base of the Haight Creek are rare in the Cedar Fork. The chert of the Cedar Fork Member is offwhite, opaque, conchoidal, and subporcellaneous to stony in luster. Concentrations of chert occur in the upper portions of the member while the lower portion is relatively chert free.

The Cedar Fork occurs throughout the area of this report ranging from 10 to 30 feet in thickness. It is most typically developed in the southeastern counties.

Subsurface Characteristics in Western District

The Burlington Limestone exhibits gradational changes in lithologies from the southeastern district to the western district where dolomite beds increase at the expense of the limestone and both carbonates and cherts become darker in color. However, at Story City, Story County, (W-2158) the lithology of the Cedar Fork Member is similar to that of the southeastern district.

In the western district the Burlington is composed mainly of chert and dolomite with subordinate limestone. The chert is offwhite to light gray (N-7), commonly mottled or speckled gray, generally opaque and conchoidal. Rhombic dolomite crystals, which are often replaced by chalcedony, is a common feature. Much of the chert contains drusy quartz, and in the lower part of the formation the chert is very quartzose (Collins W-2164, Des Moines W-0369). The accompanying dolomite is light gray or light olive gray (5 Y 6/1) to dark yellowish brown (10 YR 4/2), and well crystallized with fine to medium crystalline texture; intersitial calcite cement is common. Some glauconite is present throughout but is abundant at the top and bottom of the formation. In Marshall and Story Counties, as at Clemons (W-1680) and Story City (W-2158), both the chert and dolomite contain a large amount of glauconite which gives the rock a dark green color. The glauconite occurs as greenish-black grains or pellets with rounded and polished surfaces.

The Haight Creek and Cedar Fork Members are present in the western district, but the Dolbee Creek appears to be confined to the southeast as shown in plate 3. Even where the Cedar Fork has been dolomitized the ghosts of the original calcarinite structure can be observed. The presence of glauconite in the Cedar Fork also helps to distinguish this member from the underlying Haight Creek Member and the overlying Keokuk Limestone. The thickness of the Haight Creek in the western district averages 70 feet; the thickness of the Cedar Fork averages 20 feet.

The glauconitic dolomite zone marking the base of the Haight Creek Member in the southeastern district extends beyond the limits of the Dolbee Creek Member and rests on Kinderhook rocks in the western district. Above the concentration of glauconite the rock in well cuttings appears to be a slightly argillaceous, silt-textured dolomite; however, after treatment in acid the percentage of residue is high and is partly argillaceous and partly siliceous forming a delicate spongy mass full of silt-sized dolomolds (Hedrick, Keokuk County, W-1307). In some samples, the interstitial material is not completely joined resulting in a silty residue, as at Des Moines, Polk County (W-0369 and W-0490). Generally a few chert fragments occur at this horizon. The distinctive nature of the insoluble residue identifies the horizon in a few wells where glauconite is absent.

Although this report is confined to the southeastern quarter of Iowa, the Cedar Fork and Haight Creek Members are recognized in well cuttings from other areas in the State. The Dolbee Creek, Haight Creek, and Cedar Fork have been recognized in well cuttings from adjacent counties in Illinois and Missouri.

Sedimentation and Diagenesis

The Burlington Limestone originally was a bioclastic limestone. The texture is controlled largely by the crinoidal stem and plate fragments and is rather coarse ranging from calcarenite to calcirudite. Some fine-textured limestone beds are interstratified with the coarser beds. Exposures of the formation show massive continuous bedding, which are commonly cross laminated. Neither quarry exposures nor subsurface data indicate biohermal structures or bar development.

The original limestone has been diagenetically altered. The fossil fragments were recrystallized and interstices ultimately became filled by clear calcite, which commonly was grown in crystalline continuity to the recrystallized fragments. Many beds were subsequently dolomitized. In the southeastern district, the limestone in some beds has been replaced by dolomite crystal rhombs. In the western district dolomitization is complete. As a result of this diagenesis, distinct carbonate lithofacies are recognizable.

The exact nature and origin of the chert is a moot question. The even and continuous chert beds that are seen in many quarries would seem to indicate a primary origin. Nevertheless, the enclosed fossil fragments, at least, have been diagenetically silicified. Furthermore, many of the dolomites contain a large chert residue, which may represent siliceous interstitial filling, although much is considered to be formed by replacement. The cherts of the Haight Creek Member commonly contain euhedral dolomite crystals, although many of these rhombs are now chalcedonic pseudomorphs.

Keokuk Limestone

General Statement

The Keokuk Limestone was named by Owen (1852), for those beds underlying the Archimedes limestone and overlying the Burlington Limestone. Hall (1857), expanded the Keokuk to include the Archimedes limestone and the 40 feet of calcareous shale containing numerous geodes of quartz and chalcedony which overlies the limestone. These beds he termed, "The Geode Bed." Owen applied the term "Keokuk cherty limestones" to the beds which Hall referred to as the "cherty beds of passage" separating the Keokuk and Burlington. These beds were later called "Montrose cherts" by Keyes (1893). The name "Keokuk" has been used in various ways by different geologists, but it is now used by the Iowa Geological Survey as defined by Van Tuyl (1922): "The Keokuk formation consists of the transition beds known as the Montrose cherts, which are about 30 feet in thickness, and the Keokuk limestone, which is about 40 feet in thickness."

In subsurface, the Keokuk Limestone is readily recognizable in the region of the type locality. The "Montrose cherts" are easily identified overlying the relatively noncherty Cedar Fork Member of the Burlington Limestone. The top of the Keokuk cannot be identified as readily. The upper Keokuk Limestone is composed of gray, fossiliferous calcarenites with interbedded, fossiliferous, calcareous shales. The shale beds increase in number and thickness upward, grading into the gray Warsaw shales, and dolomite beds replace the limestone. Van Tuyl's boundary occurs in the transition. In subsurface usage, the upper boundary of the Keokuk is generally placed at the top of the calcarenite. This usage may raise the boundary slightly to include Van Tuyl's basal limestone unit of the lower Warsaw, because it is lithologically similar to the uppermost Keokuk.

Distribution and Thickness

The Keokuk Limestone is exposed only in parts of Lee, Des Moines, Louisa, Henry, Keokuk, and Van Buren Counties. In subsurface it extends into central Iowa and southwestward into Missouri, Nebraska, and Kansas. The regional distribution in central United States is similar to that of the Burlington, outcropping in Illinois, Missouri, Arkansas, and northeastern Oklahoma. Rocks believed to be of comparable age occur in Indiana, Ohio, and Kentucky, but they are largely of terrigenous origin.

In subsurface of the southeastern district, the thickness of the Keokuk where overlain by the Warsaw Formation averages about 75 feet. It ranges from 100 feet at Keokuk, Lee County (W-1282) to a minimum of 37 feet at Wayland, Henry County (W-1332). In the western district it averages 50 feet. A maximum of 125 feet was found at Des Moines, Polk County (W-0369); it is thinner north of Des Moines in Story and Marshall Counties where it averages 25 feet.

Subsurface Characteristics in Southeastern District

The "Montrose cherts" are described as consisting of alternating layers of gray and blue cherty limestones in which several brachiopod species typical of the Keokuk appear for the first time. The upper beds ". . . consist of layers of gray to bluish limestone, alternating with beds of shale, which are increasingly prevalent and thicker towards the top" (Van Tuyl 1922).

The lower "Montrose cherts" and upper "Keokuk limestone" are easily recognizable in the southeastern district (fig. 12A). The lower portion of the Montrose unit generally contains a very pale-orange (10 YR 8/2) and gray, medium to coarsely crystalline limestone grading into calcarenite. Fossil fragments, espe-

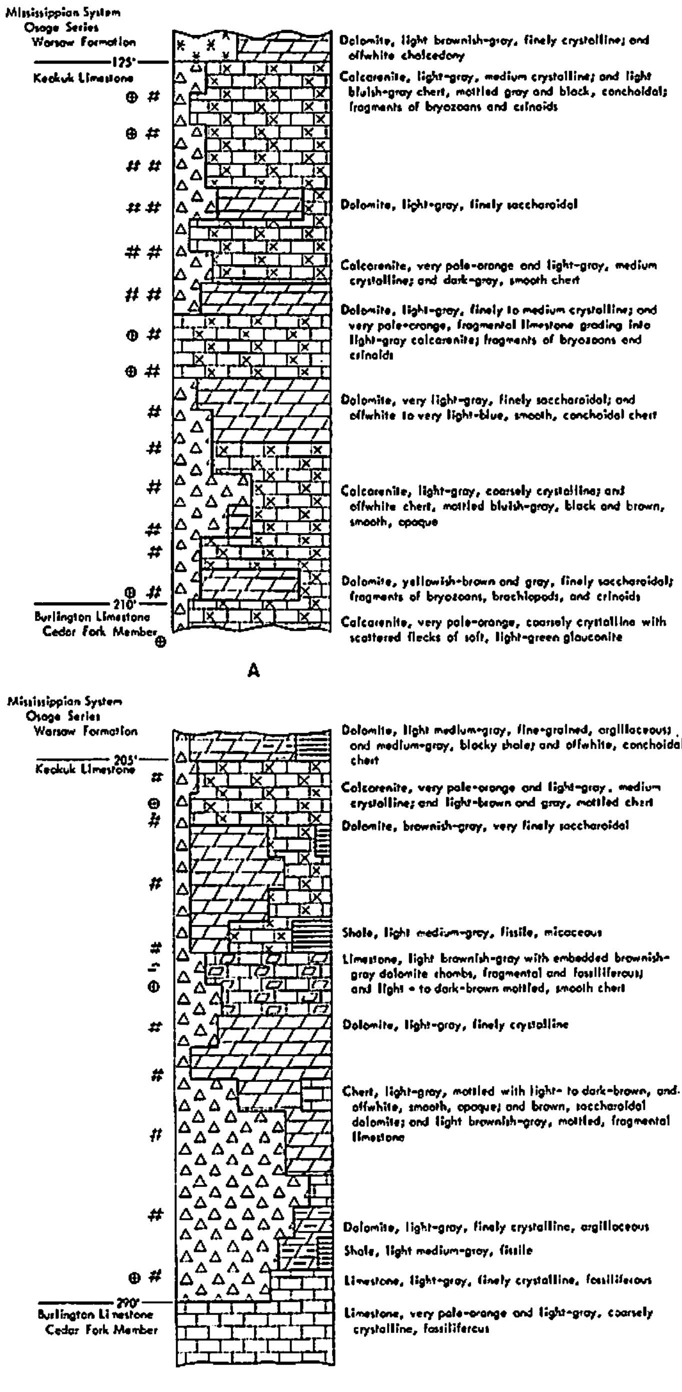


Figure 12. Percentage logs of well cuttings from Keokuk Limestone at A. Max Bollin farm, Lee County (W-11048), B. Northwest Mutual Life Insurance Company, Jefferson County (W-1480). Key to symbols given in figure 2.

cially of brachiopods and crinoids are common (pl. 5, fig. 1). Dolomite beds, composing about 50 percent of the carbonates of the "Montrose" unit are light gray to light olive gray and fine to medium crystalline. Most of the dolomite contains interstitial siliceous material and some is argillaceous. A few intercalations of gray, generally non-fissile, dolomitic shale are present. Chert is the dominant lithology in well cuttings through the upper portion of the Montrose cherts, although the percentage is undoubtedly exaggerated through drilling and sampling techniques. The chert is typically light gray and offwhite mottled and specked with black, gray, or brown; it is cryptocrystalline, opaque, breaks with a conchoidal fracture, and has a stony luster (pl. 5, fig. 2). Spicular fragments of fossils are abundant in the chert and serve to distinguish the Keokuk from the dominantly crinoidal chert of the Burlington.

The upper part of the Keokuk is typified by light-gray calcarenites. This unit is thick and well developed in some localities as at Keokuk, Lee County (W-1282) and Keosauqua, Van Buren County (W-0669) and only poorly shown in others, as in the Bengston well (W-2150) near Denmark, Lee County. The calcarenite is very pale orange to gray, commonly with darker mottlings (pl. 5, figs. 3 and 5). In many cases the fossil fragments constitute the darker component. The fine-grained matrix is mostly pure calcium carbonate with a small amount of gray argillaceous material. Quartz sand has not been observed in the Keokuk. The accompanying chert is gray and light bluish gray (5 B 7/1), mottled and specked offwhite and black; it is opaque and has a conchoidal fracture and subporcellaneous luster. Brown chert occurs with the gray in some well cuttings; the amount of brown chert increases toward the west (Montrose, Lee County W-2290; Danville, Des Moines County W-1572; Rome, Henry County W-1806; Richland, Keokuk County W-2387). Dolomite beds also occur in this portion of the Keokuk and may be dominant as at the Iowa Wesleyan College farm well, Henry County (W-1804). The dolomite is light medium gray, fine to medium crystalline, commonly argillaceous and grades into a chunky dolomitic shale that has about the same color. Micaceous, fissile shale is present at some localities. Glauconite, as scattered soft, green spots, is associated with the Keokuk sediments, but a concentration has not been noted at any single horizon over a broad area, as it has in the Burlington.

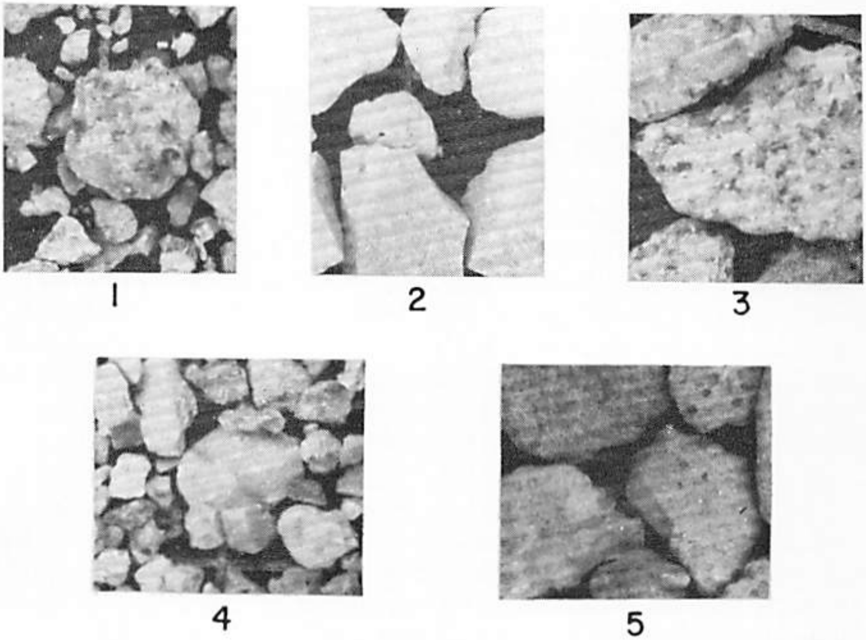


Plate 5. Photomicrographs of representative well cuttings of the Keokuk and the Warsaw Formations X-7.

1. Montrose chert (W-7981, 210' -215') limestone, coarsely crystalline, crinoidal.
2. Montrose chert (W-8167, 175' -180') typical chert, light gray and offwhite, mottled and specked with gray and brown; dolomite, light gray, fine to medium crystalline.
3. upper Keokuk (W-8167, 135' -140') light gray calcarinite, with darker mottlings by fossil fragments; chert (upper left) light gray, speckled, opaque and conchoidal; dolomite (lower right) gray, argillaceous, finely crystalline.
4. upper Keokuk (W-7981, 185' -190') light gray calcarenites; mottled chert and chunky dolomitic shale.
5. Warsaw (W-8167, 105' -110') chalcedony rosette (lower left); shale (upper left) medium gray, chunky and dolomitic; dolomite, finely crystalline and argillaceous.

Subsurface Characteristics in Western District

The Keokuk Limestone in the western district is typically brown—dark in the upper portion and lighter below. The most striking lithology is the brownish-gray chert which is mottled white and contains white spicules; it is conchoidal, opaque, and has a stony luster (fig. 13 B). A chert of similar appearance but with a very grainy texture, reminiscent of the grainy chert of the middle Hampton in southcentral Iowa, was noted in some well cuttings. The carbonate in this district is chiefly dolomite rather than limestone and is characteristically brown, finely crystalline, argillaceous and highly siliceous. Brown to olive-gray, blocky, dolomitic shale is a third lithology typical of the formation. The lower part of the Keokuk contains a large amount of secondary siliceous material in the form of crystalline quartz and chalcedony, probably of geodal origin.

Sedimentation and Diagenesis

The sediments of the lower Keokuk are little different from those of the Burlington. They originated as bioclastic sands, consisting largely of fossils and fossil fragments. The interstices are filled with opaque microcrystalline carbonate, probably of authigenic origin. Argillaceous material increases upward. The upper Keokuk is similar calcarenite but much more argillaceous.

Shales interbedded with the calcarenites are fossiliferous and calcareous or dolomitic. Fossil fragments of brachiopods and crinoids and especially bryozoan masses are enclosed in the shale.

Dolomitization of the limestone is widespread, although not always complete even in the western district. The dolomite is commonly medium crystalline and rather dense. In the southeastern district the mottling of the original limestone is preserved in the dolomite and the original calcarenite structure is discernible in both surface exposures and in well cuttings.

Silicification follows the same pattern as that in the Burlington. Some is diagenetic, including silicification of fossil fragments and interstitial filling of some of the clastic limestones.

Warsaw Formation

General Statement

The Warsaw, or Second Archimedes Limestone, was named by Hall (1857) for 18 feet of highly fossiliferous beds of blue shale with intercalations of thin-bedded, impure limestone from exposures at Warsaw, Hancock County, Illinois. A typical exposure occurs along a creek known as Soap Factory Hollow which joins

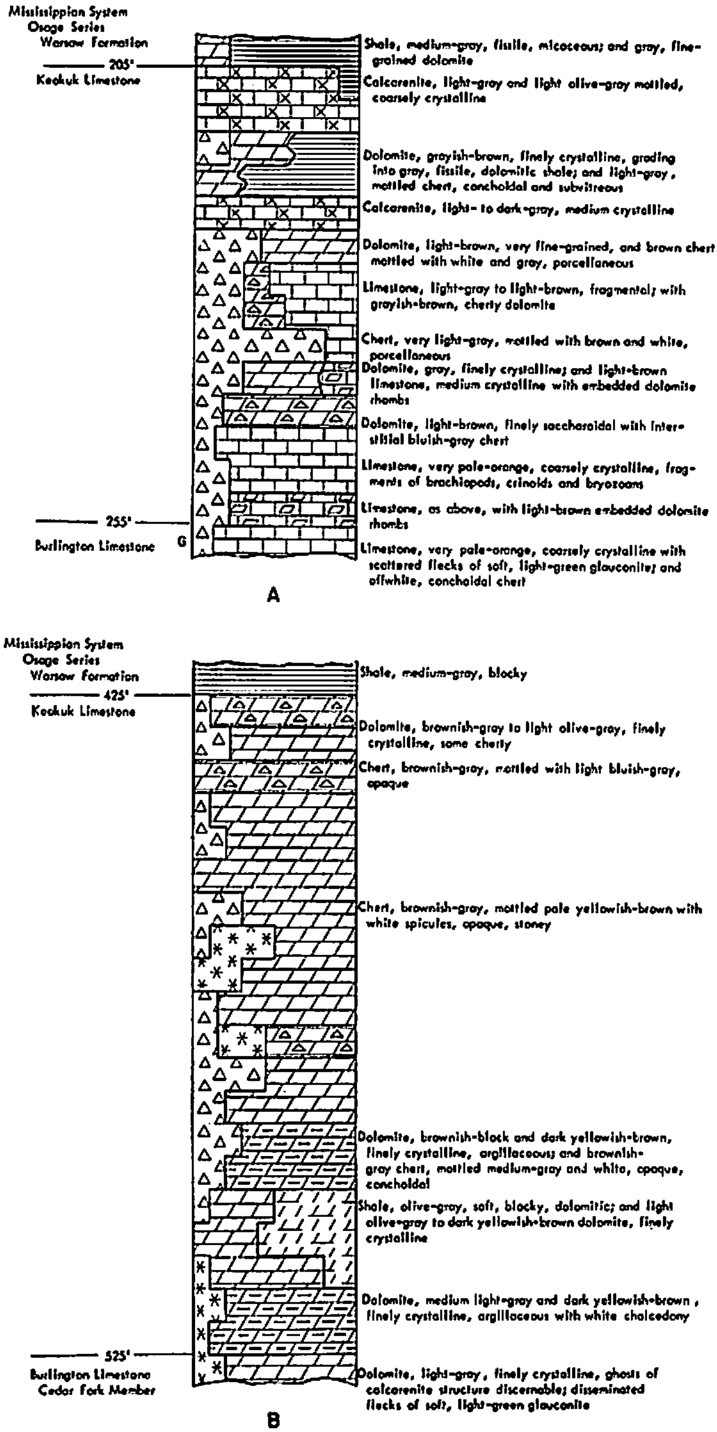


Figure 13. Percentage logs of well cuttings from Keokuk Limestone at A. Richland town well, Keokuk County (W-2387), B. Polk County Conservation Commission (W-10531). Key to symbols given in figure 2.

the Mississippi River from the east approximately half a mile south of Warsaw, Hancock County, Illinois. He later (1858) expanded it to include about 50 feet of interbedded, calcareous shales and limestone lying between the geode beds and the overlying St. Louis Limestone. Stuart Weller (1908) separated the Spergen beds from the Warsaw and included them with the St. Louis. Van Tuyl (1922), removed the geode beds from the underlying Keokuk Limestone and included them in the Warsaw on the basis of closer affinity of the fauna to the Warsaw than to the Keokuk. The Warsaw Formation in Iowa conformably overlies the Keokuk Limestone and is unconformably overlain by the Spergen.

In subsurface, the lower boundary of the Warsaw Formation is not readily recognizable. The underlying Keokuk Limestone, though primarily composed of calcarenites, contains shale beds which increase in number and thickness toward the top. The lower Warsaw contains similar calcarenites. The boundary between them is nebulous and arbitrarily placed for uniformity, at the top of the gray calcarenites in the southeastern district and at the top of the brown dolomites and brown cherts in the western district. The upper boundary is more easily recognized. Presence of terrigenous quartz sand in the overlying Spergen clearly marks the upper limit of the Warsaw. Where the Spergen is absent, the Warsaw is overlain by the sandy limestones or dolomites of the St. Louis.

Distribution and Thickness

The Warsaw Formation has a regional distribution in central United States similar to that of the Keokuk. In Iowa it is exposed only in Lee, Des Moines, Louisa, Henry, Van Buren, and Keokuk Counties.

The bluffs in the south part of the town of Keokuk, Lee County, have a vertical exposure of approximately 70 feet including the rocks of the upper Keokuk Limestone, the complete Warsaw Formation, the Spergen Formation, and most of the St. Louis Limestone. Here the Warsaw is 44 feet thick. The Warsaw is exposed in contact with both the Keokuk and Spergen Formations in a road cut exposure 4 miles northwest of Augusta, Des Moines County, where the Warsaw is only 24 feet thick.

In subsurface, the Warsaw occurs over most of the area of this report. The greatest recorded thickness of 85 feet is at Keosauqua, Van Buren County (W-3796). The average thickness for the formation in the southeastern district is 50 feet.

It thins to the northwest to an average of 25 feet. The placement of the Warsaw-Keokuk boundary is difficult in Polk, Story, Marshall, and Jasper Counties where the underlying Keokuk Limestone becomes more shaly and the calcarenites have been replaced by argillaceous dolomite. Here a section of 20 to 25 feet may have questionable affinities (fig. 15 A and B).

Subsurface Characteristics

Van Tuyl (1922) divided the Warsaw into the upper and lower members from the faunal evidence and the dominance of the geodes in the lower beds. Lithologically the two members are very similar, consisting primarily of blue-gray calcareous shales, and fragmental, fossiliferous, dolomitic limestone.

In subsurface the Warsaw is characterized by shale, dolomite, and chalcedonic chert lithologies (pl. 5, fig. 5). Shale is dominant in the upper portion whereas the chalcedony tends to be concentrated in the lower portion (figs. 14 and 15).

In the southeastern district the shale of the Warsaw is primarily very light gray to medium gray, chunky, and dolomitic. Fenestrate bryozoans are preserved in the shales. Very light-gray to light medium-gray, finely crystalline, argillaceous dolomites accompany the shales. In the western district, both the shales and the dolomites are darker, ranging from medium gray to light brownish gray.

The chalcedony is associated with crystalline quartz and undoubtedly represents broken geodes. It is botryoidal, commonly in concentric masses or in the form of rosettes with chalcedonic centers surrounded by quartz. Typically the color is light bluish gray and bluish white, but some is moderate reddish orange or moderate pink.

The carbonate rocks interstratified with shale are more numerous in the lower portion of the formation. In the outcrop area, both in surface exposures and in well cuttings, these are calcarenites, somewhat dolomitic. However, they have been altered in most of the area of study to finely crystalline dolomite. Ghosts of the original fragments are often recognizable. Argillaceous dolomites are the dominant lithology in the western district probably because the shaly upper Warsaw has been largely removed by post-Osage erosion.

Sedimentation and Diagenesis

The sediments of the lower Warsaw are similar to those of the upper Keokuk. They originated as bioclastic sands with con-

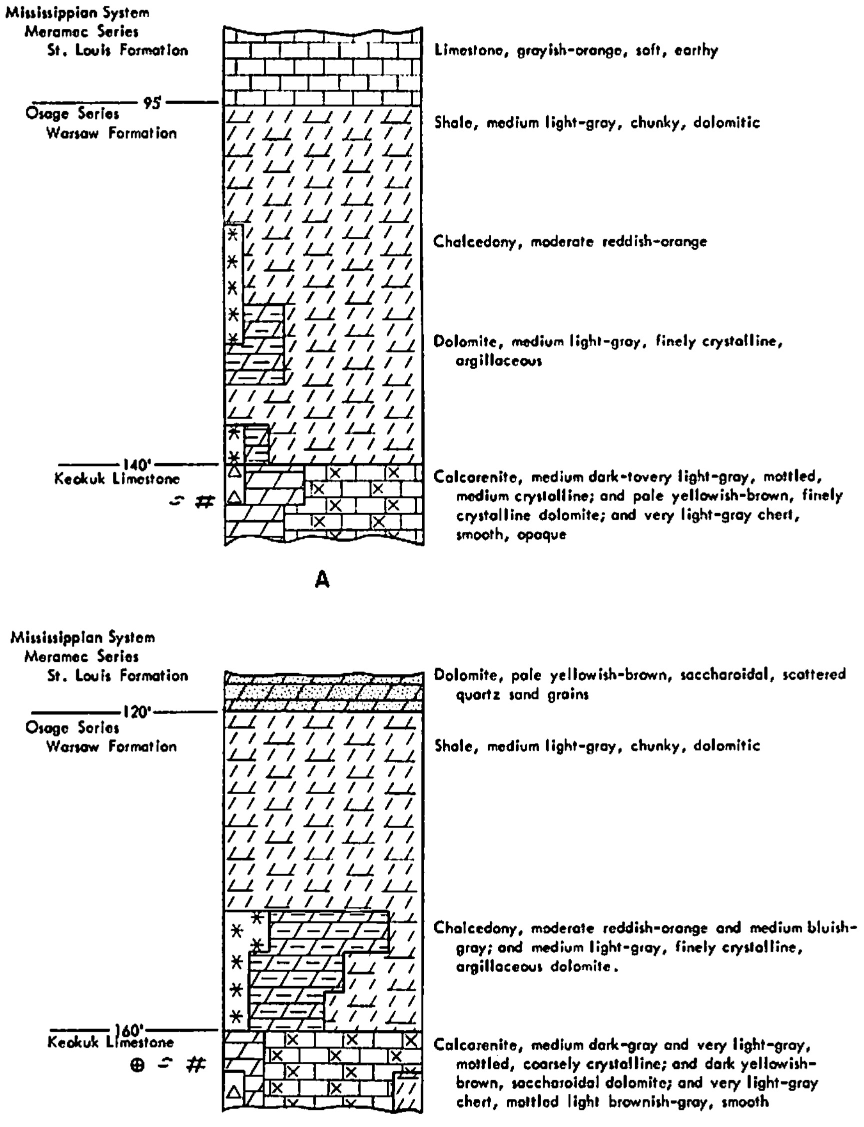
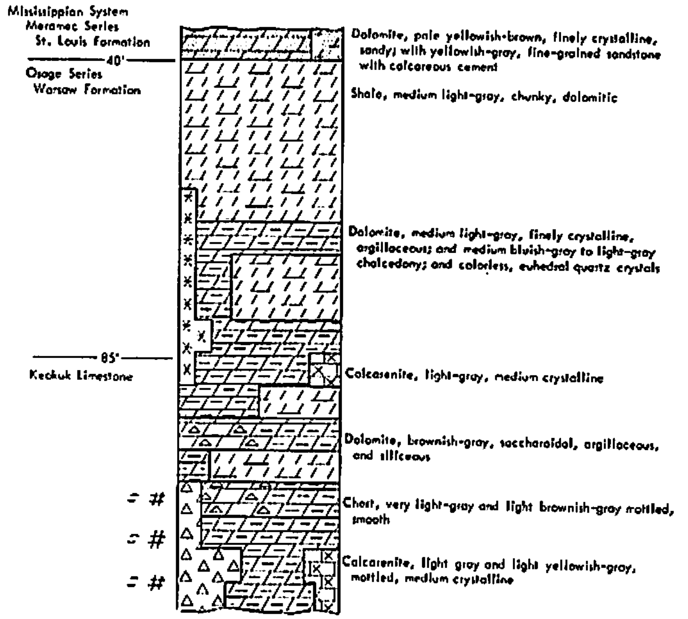


Figure 14. Percentage logs of well cuttings from Warsaw Formation illustrating the greater abundance of chalcedony and dolomite in the lower portion of the Warsaw at A. Geode State Park, Henry County (W-7849), B. Charles Frank farm, Des Moines County (W-7981). Key to symbols given in figure 2.



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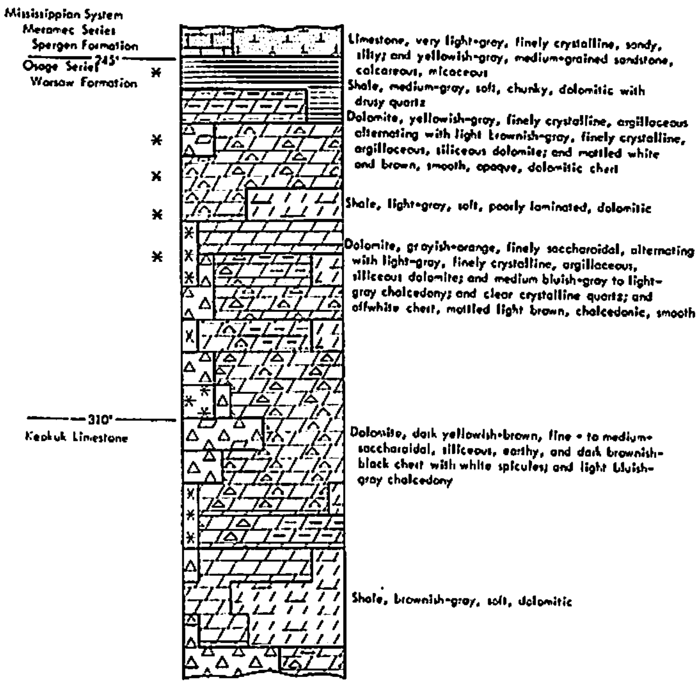

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Figure 15. Percentage logs of well cuttings illustrating gradational lithologic changes between the Keokuk and Warsaw Formations at A. Walter Boyd farm, Henry County (W-6945), B. Robert Tobin farm, Jasper County (W-10662). Key to symbols given in figure 2.

siderable incorporated argillaceous material. The proportion of argillaceous material increases upward until the sediments of the upper Warsaw are primarily calcareous muds. The shales as well as the interbedded marly calcarenites are fossiliferous and dolomitic. Fenestrate bryozoans are the dominant fossils, but fragments of brachiopods also occur.

Dolomitization of the limestone is nearly complete throughout the area of this report. In the southeastern district the dolomite is finely crystalline and argillaceous, and ghosts of the original fragments are discernable. Siliceous material of the Warsaw sediments is in the form of geodes. Silicification of fossil fragments or interstitial filling of the clastic limestones has not been observed.

SUMMARY OF DISTINGUISHING CHARACTERISTICS

This summary of the criteria for recognition of the divisions of the Osage Series is included primarily as a convenient reference for those who work with subsurface stratigraphy.

The distinctive features for recognition of the division of the Osage Series in subsurface are graphically portrayed in figure 16. This shows horizontal as well as vertical distinctions. Photomicrographs of some well cuttings of the major units illustrate the lithologies (pls. 4 and 5).

Recognition of the divisions is easiest in the limestone facies of the southeastern district. Farther west, dolomitization has masked some of the primary features. Nevertheless each formation has its characteristic aspects.

The Burlington Limestone is readily distinguished from the overlying and underlying formations by the pure offwhite to very pale-orange, crinoidal, coarsely crystalline limestone which composes the Cedar Fork and Dolbee Creek Members. The underlying Hampton Formation is a brown or yellowish-brown, medium crystalline dolomite, and the overlying Keokuk is a gray or brownish-gray cherty, argillaceous limestone or dolomite. Typically the chert of the Burlington is nearly white with light-colored mottles and crinoid fragments. It is generally distinguishable from that of the Keokuk by the lack of gray or brown mottlings, although such coloring does occur in the Burlington in some localities. The chert of the Haight Creek Member is characterized by dolomite rhombs that are commonly replaced

Western district

Shale, gray, dolomitic

Dolomite, gray, finely crystalline, argillaceous; and, chalcedonic chert; and gray dolomitic shale

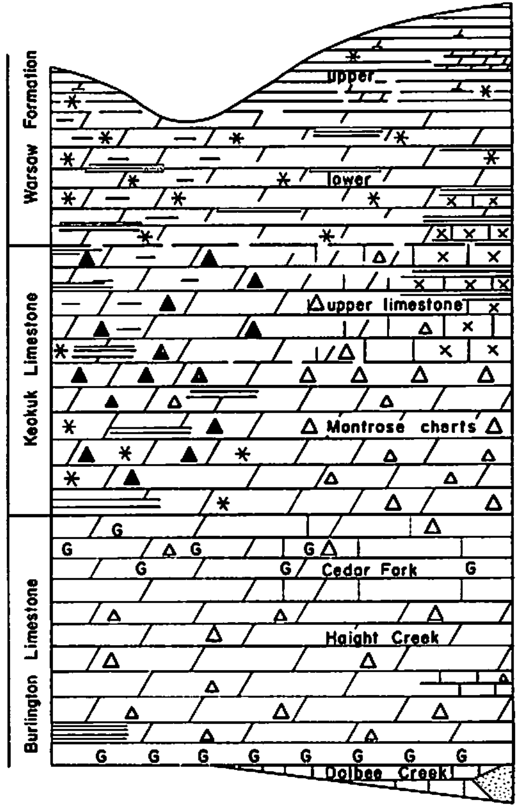
Dolomite, brown, medium crystalline, argillaceous; and brown chert with white spicules; and brown shale

Crystalline quartz and chalcedony

Dolomite, light-gray, coarsely crystalline; and white, porcellaneous chert; and scattered soft flecks of light-green (5 G 5/3) glauconite

Dolomite, dark-gray, finely crystalline; and offwhite to light-gray, mottled chert with rhombic dolomite crystals

Dolomite with silty or siliceous interstitial filling and gray dolomoldic shale; and greenish-black (5 G 2/1), rounded, polished glauconite pellets



Southeastern district

Shale, gray, dolomitic; and dolomitic calcarenite

Dolomite, finely crystalline, argillaceous; and dolomitic calcarenite; and gray dolomitic shale; and chalcedonic chert

Calcarenite, mottled gray or brown, microcrystalline matrix; and gray or brown shale

Chert, gray, speckled black or grayish-brown; and gray or brown, argillaceous dolomite; and calcarenite, coarse crinoid fragments with sparry cement, darker than below

Calcarenite, light gray, very coarse crinoid fragments with sparry cement; and white, tripolitic to porcellaneous chert; and scattered soft flecks of light-green (5 G 5/3) glauconite

Dolomite, finely crystalline; and white, mottled gray, fossiliferous chert; and greenish-black (5 G 2/1), rounded, polished glauconite pellets

Calcarenite, medium to coarsely crystalline; and locally sandstone, quartz overgrowth

Figure 16. Distinguishing characteristics of the Osage rocks from the subsurface in southeastern Iowa. Key to symbols given in figure 2.

by chalcedony. Concentrations of glauconite occur at two horizons. The base of the Haight Creek is marked by an impure dolomite zone containing as much as 20 percent greenish-black, rounded and polished glauconite grains. The Cedar Fork Member at the top of the Burlington is likewise very glauconitic, but the glauconite occurs in soft grayish-green flecks and a concentration of this mineral near the top of the member is an important criterion for separating it from the overlying Keokuk Limestone especially in the western district.

Where locally present, in the east, the basal conglomerate and sandstone is an excellent marker between the Burlington Limestone and the Hampton Formation. It is very different in character from the other quartz sandstones of the Mississippian System of Iowa. The English River and Prospect Hill Formations of the Kinderhook Series are quartz siltstones, gray in color, and very well sorted. The sandstone of the basal Burlington is white or yellowish, not as well sorted, and contains weathered chert and dolomite. Sand grains in the Meramec formations are typically "St. Peter" type, rather well rounded, frosted, and pitted. Secondary enlargement of the sand grains is not well developed in the formations of the Meramec Series, but is well developed in the siltstones of the Kinderhook Series and the sandstone of the Burlington.

Dolomites of the Hampton are generally brown and are composed of saccharoidal rhombohedral crystals, commonly with clear, sparry calcite. Such void fillings are not common in the Burlington dolomites. West of the outcrop area the chert of the underlying Hampton Formation has an ash-gray color. It breaks with a conchoidal fracture, has a stony luster and a distinctive stippled appearance in some localities. It has a rough mealy texture and dull luster in other localities. Brown shaly partings are typical of the dolomites of the Hampton. Ghosts of oolites occur in much of the dolomite overlying the Hampton cherty dolomite and directly underlying the Burlington Limestone in Keokuk, Mahaska, Wapello, and Monroe Counties. This may represent a southeastward extension of the complex stratigraphic sequence of Gilmore City - Iowa Falls - Eagle City. The interbedded limestones associated with these oolites are very pale orange or pinkish gray, densely microcrystalline, opaque, and commonly oolitic. These are very different from the limestones of the Burlington. The typical Gilmore City oolitic calcarenites, which are locally dolomitized, underlie the Burlington in Story, Marshall, Polk, Jasper, Warren, and Marion Counties.

An excellent horizon marker occurs above the concentration of glauconite at the base of the Haight Creek and below a high chert concentration. This interval is commonly 10 feet in thickness and is composed primarily of light-gray, soft, blocky, shale containing dolomite rhombohedrons. The accompanying dolomite is also light gray to medium light gray, is finely crystalline and contains a high percentage of argillaceous residue. In some cases the residue of the dolomite is argillaceous, siliceous, and dolomoldic, and retains the form of the well-cutting fragments. This interval is believed to be equivalent to the medium-gray, silty-textured, argillaceous dolomite observed above the heavy glauconitic zone at the base of the Haight Creek in quarries and well sample cuttings in Washington and Keokuk Counties (fig. 11 B).

The contact between the Burlington and Keokuk Limestones is more difficult to establish in the west than in the east. However, where present, the offwhite crystalline limestone of the Cedar Fork Member clearly marks the top of the Burlington Limestone. This unit is generally glauconitic and is therefore identifiable even when dolomitized. The dolomite is generally lighter in color than the dolomite of the Keokuk. The cherts of the Burlington are offwhite to light gray, conchoidal, opaque, and stony, whereas the lower part of the Keokuk contains a large amount of chalcedony. In the extreme western portion of the area, shale beds occur at the base of the Keokuk, but are rare in the Burlington. The most distinctive chert of the Keokuk is dark brown with disseminated white spicules; it breaks with a conchoidal fracture and has a stony luster. The accompanying dolomite is also dark brown, siliceous, and when treated with acid commonly leaves brown argillaceous flakes as residue.

The distinguishing criteria for the recognition of the Warsaw Formation in subsurface are the chalcedonic cherts and dolomitic shales. Where the Warsaw and Keokuk Formations are both dolomite, the boundary is difficult to place. There is a gradation from the browner, coarser-textured Keokuk to the grayer Warsaw. Where present, the mottled gray or brown cherts of the Keokuk and the chalcedonic cherts of the Warsaw serve to distinguish the formations. The dolomite of the Warsaw does not contain the quartz sand that is so characteristically disseminated through the dolomites of the overlying Spergen and St. Louis Formations.

Stratigraphic Relationships

The regional unconformity at the base of the Burlington Limestone recognized by Laudon (1937), is confirmed by the results of this study. Laudon also noted a transgressive overlapping of the younger beds of the formation toward the north and west. In subsurface this relationship is readily apparent in southeastern Iowa where the crinoidal limestone, Dolbee Creek occurs only in the southeastern counties (pl. 3). The sandstone at the base of the formation in Washington County is also significant in this regard. Further evidence of the unconformity is the fact that the Burlington Limestone rests on progressively younger beds westward from the city of Burlington, Des Moines County.

The Keokuk Limestone overlies the Burlington conformably. In the southeastern district the boundary has been placed at the base of the Montrose cherts where changing depositional environments are indicated by a change from offwhite rather pure deposits of chemical origin to gray rocks containing argillaceous material of terrigenous origin. The contact with the Burlington in the western district appears to be gradational, and a zone about 20 feet thick has questionable affinities. In some wells (Des Moines W-0369), (Melbourne W-0908), however, there is a blocky, brownish-gray shale 5 to 10 feet in thickness at the base of the Keokuk.

In central Iowa the Keokuk Limestone is characterized by brown sediments and considerably more shale than in the east. The upper 50 feet, especially, consists of dark-brown deposits of chert, dolomite, and shale. A gradual change in lithologic characteristics from the base upward and from the east to west shows that this unit belongs to the Keokuk. The gray fissile Warsaw shales generally overlying the Keokuk Limestone in southeastern Iowa are not well developed in central Iowa and are entirely absent in many localities. In such places the dark brown unit of the Keokuk is overlain by the sandy dolomite of the Spergen Formation.

The Warsaw Formation conformably overlies the Keokuk Limestone. Lithologically the Keokuk appears to grade upward into the younger Warsaw sediments. The two formations appear to complement one another in thickness and facies alterations. Cores from Geode State Park in Henry and Des Moines Counties do not show any sharp break in sedimentation, but rather alterations of shale and limestone—the former increasing, the latter decreasing upward. A boundary on lithologic evidence appears to be more or less arbitrary. The combined thickness of the two formations is shown in plate 6.

The overlying Spergen-St. Louis is marked by the appearance of coarser terrigeneous clastics. An unconformable relationship above the Warsaw is indicated by the absence of the Spergen in some areas.

STRUCTURAL GEOLOGY

Southeastern Iowa is part of the eastern periphery of the Forest City basin as mapped by Lee (1946). His series of maps includes most of the area of this report but does not reach the eastern margin of the basin, which is marked by the Mississippi River arch. This broad arch, described and mapped by Howell (1935), separates the Forest City basin from the Illinois basin.

A regional dip toward the southwest is apparent from the outcrop pattern. The surface work of McGee (1891), Keyes (1893), Gordon (1895), and Norton (1911) in southeastern Iowa indicated parallel anticlines with their axes trending northwest-southeast parallel to the regional strike. Considerable subsurface information has accumulated in recent years which permits greater local detail. These data have further defined the anticlines noted by the earlier workers. Structural features of southeastern Iowa are shown in plate 2. The base of the Haight Creek Member of the Burlington Limestone has been used as the mapping datum.

The coincidence of the structural lows and the areas of thicker accumulation of sediments as shown on the thickness maps (pls. 1, 3, and 6) is striking. Along the crests of the Bentonsport and the Skunk River anticlines (pl. 2) the accumulation of Osage sediments is much thinner than in the accompanying syncline between them (pls. 1, 3, and 6). This is also true of the Burlington, Sperry, and Oquaka anticlines and their related synclines. This would indicate that this area had undergone deformation prior to or during the deposition of the Osage sediments in the southeastern counties.

The Lincoln fold of northeastern Missouri has been extended into Appanoose County, Iowa. The paucity of control makes further extension northwestward purely speculative. The Lincoln fold was probably a positive area during deposition of the Burlington Limestone and appears to define the western boundary of deposition of the Dolbee Creek Member. The greater thickness of the Burlington sediments in the Moulton city well (W-12035), Appanoose County, which is east of the fold, and the lesser thickness in the Appanoose County Home Well (W-7025) which is on the fold is indicative of this. The thickness of the Keokuk-Warsaw in these wells is within 5 feet, which suggests that the Lincoln fold was quiescent during the deposition of these sediments.

ENVIRONMENT OF DEPOSITION AND PALEOGEOGRAPHY

The Osage Series in Iowa is generally considered to represent a stable shelf environment of shallow, warm, and clear seas. Beginning with deposition of Keokuk sediments, an increasing amount of fine-grained terrigenous material was carried into the basin. An abundance of marine life inhabited these seas and their skeletal remains actually compose a large portion of the sediment.

The Burlington limestones consist mainly of disarticulated crinoidal fragments, showing little wear, deposited as beds of even thickness over the sea floor. A beach-like environment of deposition is suggested by Laudon (1957). However, the continuous, even bedding and absence of structures that might be interpreted as wave or current-built bars make such an environment questionable. It appears to the writers that the Burlington coquinas must have accumulated more or less at the site of the life habitat of the contributing organisms at depths where the bottom was agitated but not strongly acted upon by waves and currents. Thin layers of greenish shale suggest quiet rather than turbulent waters, and it is in these shales that Laudon reports the occasional occurrence of complete crinoid skeletons. Stronger current action is suggested by the cross bedding observed in some quarries, but even here no bar structures were recognized.

Biocalcarenites likewise constitute the major lithology of the Keokuk. A greater heterogeneity of skeletal remains, including abundant fragments of crinoids, brachiopods, bryozoans, and corals, shows that the sea floor was no longer dominated by crinoid colonies. The limestone contains microcrystalline carbonate and argillaceous void filling which was incorporated at the time of deposition. Argillaceous material was spread broadly over the basin and accumulated both as disseminated interstitial material and in beds of shale. The shales are themselves fossiliferous and must have accumulated slowly.

Alternating shale and limestone beds accumulated without cessation in sedimentation from Keokuk into Warsaw seas, and the same lithologies are common to both. After a time conditions changed so that the calcarenites of Keokuk-type were no longer deposited. The shales continued to enclose abundant fossil remains—although not in every layer.

The lithofacies map of the Keokuk-Warsaw Formations (pl. 7) represents the lithologies of these units as they are today. It is not a portrayal of original deposits because diagenetic changes have been responsible for extensive dolomitization and silicification. Nevertheless, inferences can be made regarding original deposition, structural conditions, and diagenetic alteration.

Four lithologies dominate the Keokuk-Warsaw Formations: dolomite, limestone, chert, and shale. These were treated in two combinations, limestone-dolomite-chert and carbonate-shale-chert as indicated by the illustrations, figure 17.

The percentage of each end-member lithology was computed for rock cuttings from each well and plotted on the diagram which was sub-divided into fields as shown on the illustration. Each lithology or combination of lithologies was assigned a symbol. Two maps were constructed, one for the carbonate-shale-chert relationships and one for the limestone-dolomite-chert relationships. The lithofacies map was then made by superimposing the two maps.

Lee County may be used as an example to illustrate the end-member plots as shown in figure 17. All of the well samples in the county were logged and the percentages of the constituents were calculated. These were plotted on triangle coordinate paper. The carbonate-shale-chert triangle shows a tight distribution mainly in the shaly carbonate division but the scatter extends into the cherty carbonate. It will be noted that a minimum of 10 percent chert, 5 percent shale, and 40 percent carbonate occurs in the well section. Many well sections fall in the tri-part division where the percentages of each end member approach equality. It is also clear that the boundary between shaly carbonate and cherty carbonate is gradational and the divisions are therefore less sharp than the lithologic terminology suggests.

The scatter is much broader on the dolomite-limestone-chert triangle. Chert content ranges from a minimum of 12 percent to a maximum of 37 percent but the range in percentages of the two carbonates is far greater. In most sections, limestone is more abundant than dolomite. The maximum range is from 92 per cent limestone to only 29 percent of the total carbonate component. These data have been integrated in the map (pl. 7) to show the lithofacies divisions. The map shows the distribution of the dominant lithologic components of the Keokuk-Warsaw, although most well sections show the presence of shale, chert, and both carbonates.

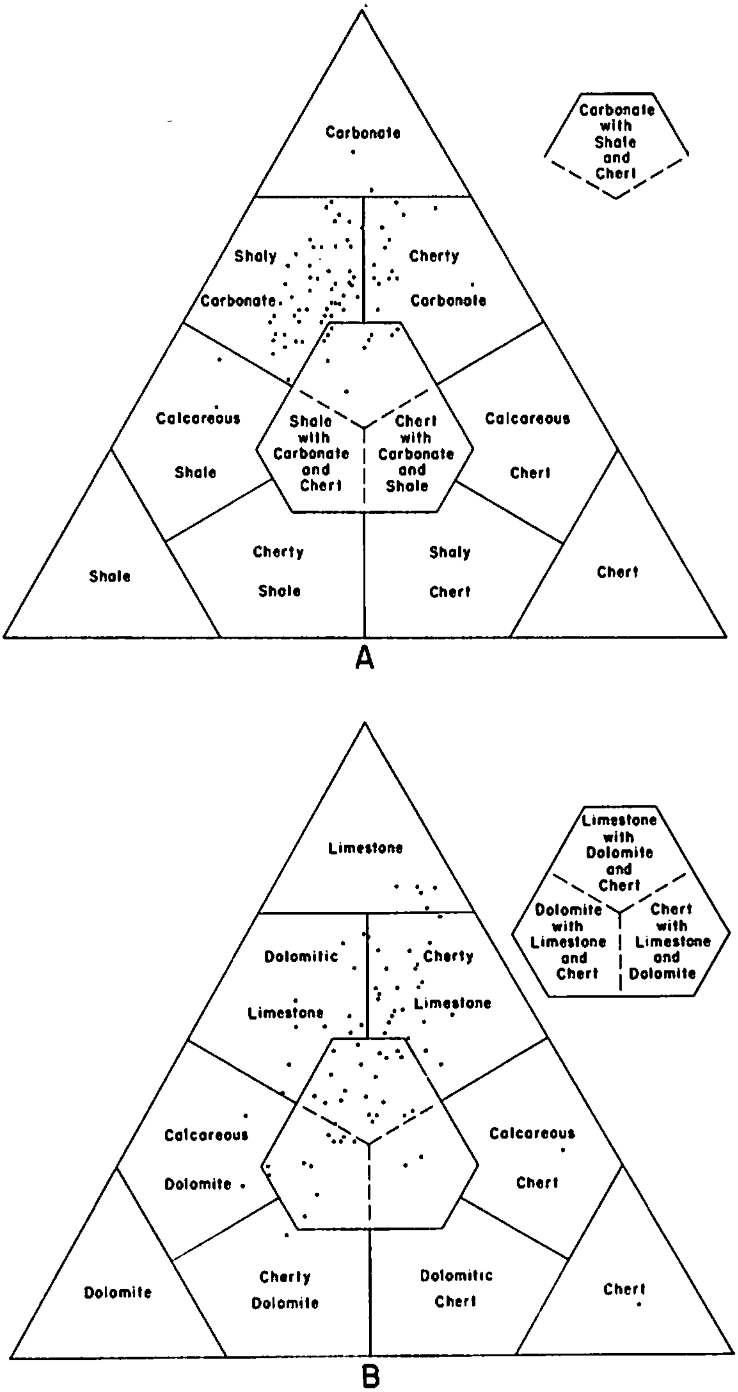


Figure 17. End-member plots of the Keokuk-Warsaw lithologies from well sections in Lee County, Iowa. A. carbonate-shale-chert components B. limestone-dolomite-chert components

Only a few well sections show a dominance of shale deposition over the carbonate. Nevertheless a shaly carbonate facies is widespread in the southern portion of the area and also occurs in central Iowa. In Des Moines, Henry, Louisa, and Washington Counties the shaly facies occurs in a loop which appears to follow synclinal areas between the Burlington anticline and the Oquaka anticline. This distribution adds credence to the theory that the structures existed at the time of deposition. Bottom sediments were winnowed of fine material in the shallower more agitated water over the structural high and carried into the adjacent troughs.

The same four-county area shows a striking distribution of the carbonate and siliceous components. Well cuttings show that sections of relatively pure carbonate occur along the axes of the structural highs. On the Burlington-Mt. Pleasant anticline an area of limestone occurs surrounded by dolomite. These relationships indicate less diagenetic alteration on the positive structures a condition the reverse of that generally noted.

The original sediments were probably limestone and shale. Dolomite and chert, now the dominant lithologies in the Keokuk-Warsaw Formations in most of southeastern Iowa, are mostly replacements of the limestone. At present it is not known whether the alteration occurred largely at the time of deposition or much later.

At the beginning of Osage time, the seas advanced northward across southeastern Iowa. During the time of Burlington deposition Ozarkia was submerged as probably was part of Wisconsia. The Mississippi River arch and the Lincoln fold were positive areas, but received sediments. The land areas were supplying little detrital or suspended materials and the only materials available in quantity were chemical precipitates and the calcareous parts of the crinoids. The sea reached its maximum extent during the Burlington. The basal standstone of the Burlington of the Washington-Louisa Counties area probably represents a shore line deposit equivalent in age to the calcarenites of the Dolbee Creek deposited off-shore in deeper waters. No other evidence of shore line deposits has been observed, although the seas must have extended further to the north than the present outcrop limits indicate.

During the time of Keokuk deposition Ozarkia and possibly Wisconsia were partly exposed but low lying; more muds were received in the depositional area. Continuing uplift and withdrawal of the sea during the time of Warsaw deposition caused more argillaceous material to be introduced and the proportion of carbonate and siliceous material decreased.

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GLOSSARY OF SELECTED TERMS

authigenic—A term applied to minerals which are originated in sediments at the time of, or after deposition. Term implies local derivation rather than matter transported.

biocalcarenite—A term applied to a limestone composed of fragments of organisms that have not been transported. Size of the particles ranges from 0.062 mm. to 1 mm.

biocalcirudite—A term applied to a limestone composed of fragments of organisms that have not been transported. Size of the particles average coarser than 1 mm.

bioclastic—A term applied to rocks which owe their fragmentation to the activities of organisms.

biogenic—A term pertaining to a deposit resulting from physiological activities of organisms.

botryoidal—having the form of a bunch of grapes.

calcarenite—A term applied to a rock composed of coral or shell sand or of sand derived from the erosion of older limestones. Size of particles ranges from 0.632 mm. to 1 mm.

calcirudite—A term applied to a rock composed of broken or worn fragments of coral or shells or of limestone fragments, the interstices filled with calcite, sand, or mud and with a calcareous cement. Size of the particles average coarser than 1 mm.

coquina—A coarse-grained, porous, friable variety of limestone made up chiefly of fragments of shells of molluscs and of coral cemented together as rock.

criquina—Limestone composed very largely of fragments of crinoids.

diagenesis—The chemical and physical changes that sediments undergo during and after their accumulation.

euhedral—A term applied to those minerals that are bounded by their own crystal faces.

interstices—A general term for pore space or openings in rock.

lithofacies—The rock record of any sedimentary environment, including both physical and organic characters.

lithofacies map—A map showing the areal variation in over-all aspect of the lithology of a stratigraphic unit.

microcrystalline—A term applied to a rock in which the individual crystals can only be seen as such under the microscope.

oolite—A rock consisting largely of small spherical or ellipsoidal accretions. The grains commonly show concentric layering or radial crystal structure, or both.

pseudomorph—A crystal, or apparent crystal, having the outward form proper to another species of mineral, which it has replaced by substitution or by chemical alteration.

sparry—A type of calcite which forms as a simple pore-filling cement, precipitated in place within the sediment. It is distinguished from microcrystalline calcite by its clarity as well as coarser crystal size.

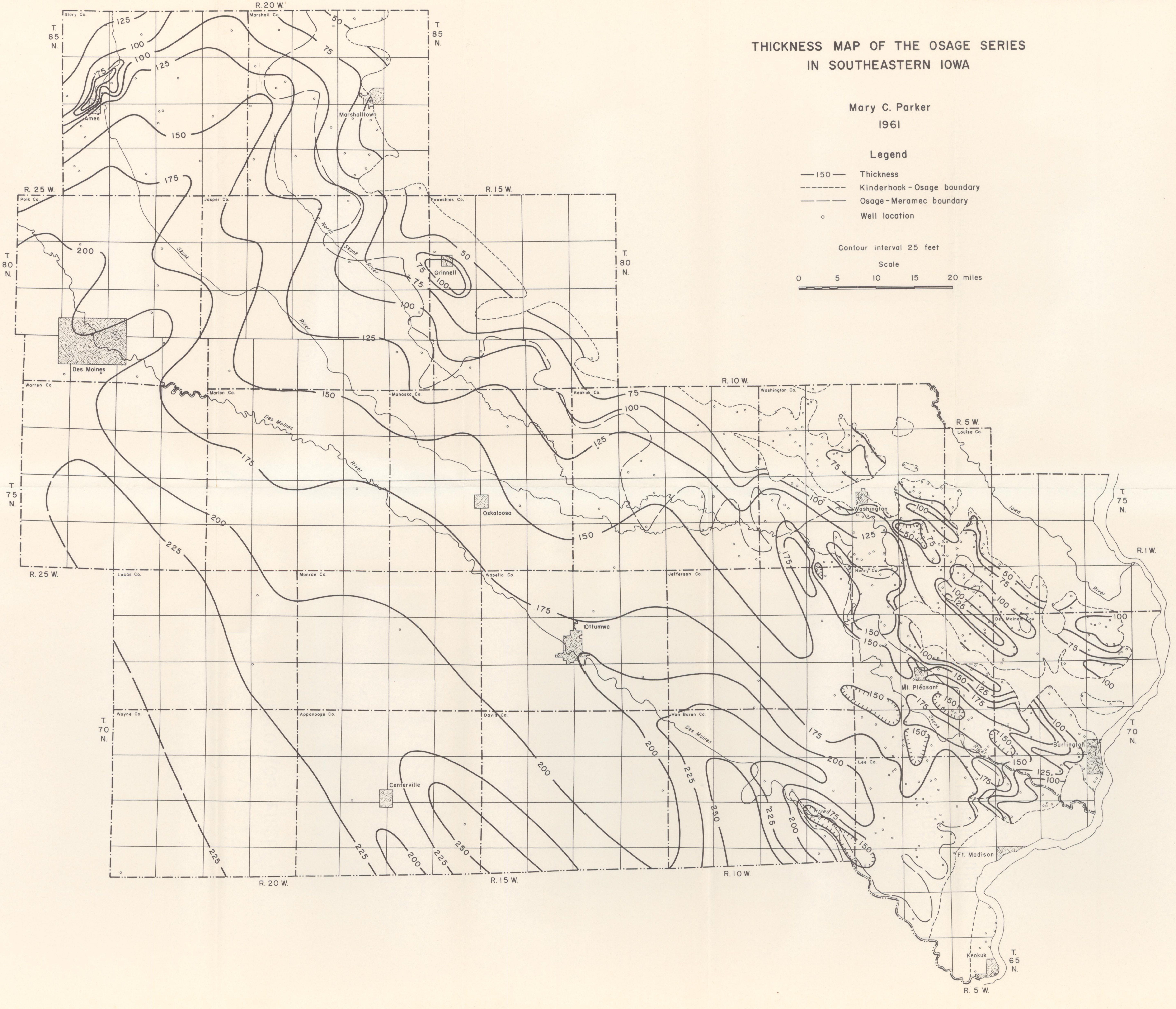
tectonic—Of, pertaining to, or designating the rock structures and external forms resulting from the deformation of the earth's crust.

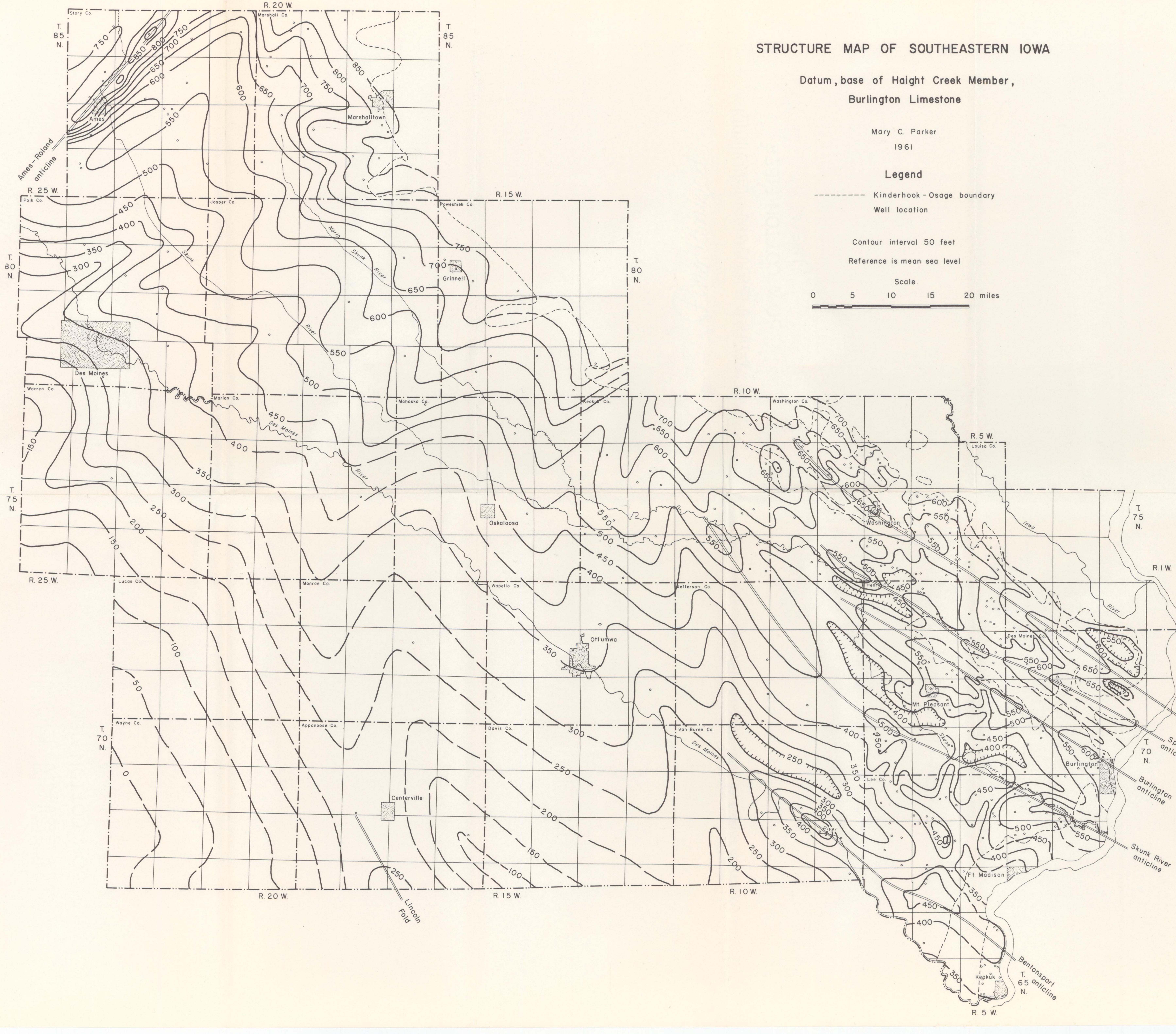
terrigenous sediments—Sediments derived from the destruction of pre-existing rocks on the earth's surface.

APPENDIX

	Quarter	Section	Township	Range
Des Moines County				
*W-1431 Iowa Ordinance Plant No. 4	NE NE NE	1	69	4W
W-1572 Danville City	NE SE NE	16	70	4W
Henry County				
W-1332 Wayland, Harry Clark farm	SE cor. NW NW	20	73	7W
W-1804 Iowa Wesleyan College farm	NE NE NW	2	70	6W
W-1806 Rome, Donald Jennings farm	SW NW NE	3	71	7W
*W-6945 Walter Boyd farm	SW NW	7	71	6W
Jasper County				
*W-10662 Tobin farm	N ½	25	80	21W
Jefferson County				
*W-1480 Northwest Mutual Life Ins. Co. farm	SE cor. NE NE	13	71	10W
Keokuk County				
W-0551 Keota City	NW cor.	25	76	10W
W-0822 What Cheer City	NW cor. SW SW	10	76	13W
W-1307 Hedrick City	NE SE NW	36	74	13W
*W-2387 Richland City	SE NW	27	74	10W
Lee County				
*W-0789 Keokuk Country Club	SW cor. NW	13	65	5W
W-1282 Keokuk, Charles Aikens farm	SE NW NW	35	65	5W
W-1385 Pilot Grove, Northwestern Mutual Insurance Co. farm	NE NW NE	22	69	6W
W-2150 Bengston farm	SE NE SW	17	69	4W
W-2290 Montrose, Conlee farm	SW NW SE	11	66	5W
*W-8167 Foecke farm	SW NW	21	69	6W
*W-11048 Max Bollin farm	NW SW	2	65	5W
Louisa County				
W-2360 Clarence Jennings farm	NW SW NW	25	74	5W
W-3874 Cotter School	SE SE SE	18	75	5W
Marshall County				
W-0908 Melbourne City	NW SW SW NE	6	82	19W
W-1680 Clemons, Dunn farm	NE SW NW	14	85	20W
Polk County				
W-0369 Des Moines, Reed Ice Cream Co.	NE cor. SW SE	33	79	24W
W-0490 Des Moines, Colonial Baking Co.	SW cor.	35	79	24W
*W-10531 Polk County Conservation Comm.	SE SE	32	81	25W
Story County				
W-2158 Story City	NE NW SE	12	85	24W
*W-2164 Collins, Wright Ringham farm	SE SE NE	12	82	22W
Van Buren County				
W-0570 Farmington State Park	SW	2	67	8W
*W-0669 Keosauqua, O. A. Parrish farm	SE	6	68	9W
W-3796 Keosauqua City	NW SE SW	36	69	10W
Washington County				
W-0686 Washington City Test No. 4	SW SW SW	17	75	7W
W-1568 Crawfordsville, Sam Turkington farm	SE NE NE	24	74	6W
W-2238 Wellman City	SE NE NE	24	77	9W

*Portion of well section graphically illustrated in the text.

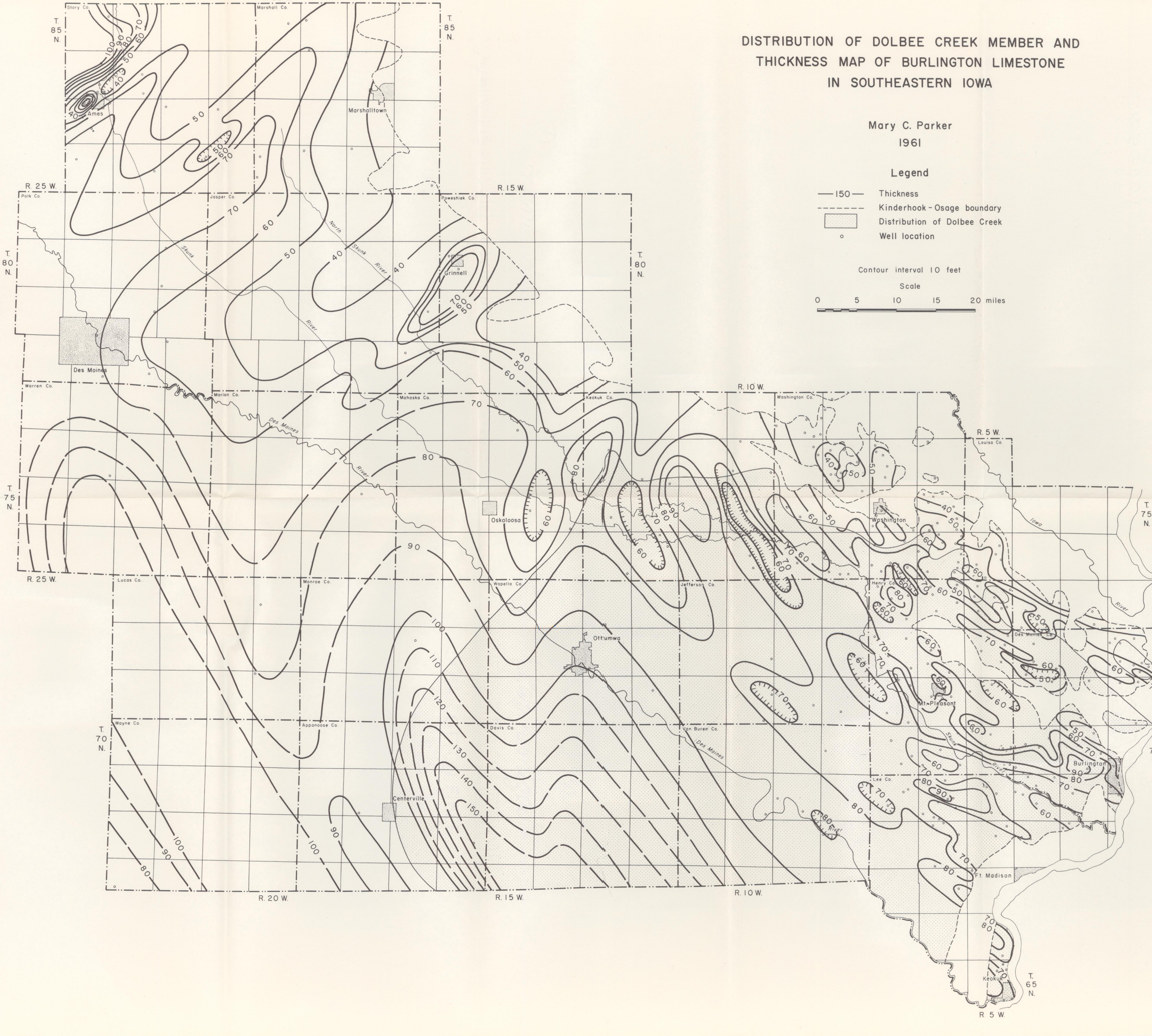

THICKNESS MAP OF THE OSAGE SERIES
IN SOUTHEASTERN IOWA
Mary C. Parker
1961
Legend
150 Thickness
Kinderhook - Osage boundary
Osage - Meramec boundary
Well location
Contour interval 25 feet
Scale
0 5 10 15 20 miles
R. 20 W.
R. 25 W.
R. 15 W.
R. 10 W.
R. 5 W.
R. 1 W.
T. 85 N.
T. 80 N.
T. 75 N.
T. 70 N.
T. 65 N.
Story Co.
Marshall Co.
Polk Co.
Jasper Co.
Poweshiek Co.
Warren Co.
Marion Co.
Mahaska Co.
Keokuk Co.
Washington Co.
Louisa Co.
Lucas Co.
Monroe Co.
Wapello Co.
Jefferson Co.
Henry Co.
Des Moines Co.
Wayne Co.
Appanoose Co.
Davis Co.
Van Buren Co.
Lee Co.
Ames
Marshalltown
Grinnell
Des Moines
Oskaloosa
Washington
Ottumwa
Mt. Pleasant
Burlington
Centerville
Ft. Madison
Keokuk
North Skunk River
Skunk River
Des Moines River
Iowa River


STRUCTURE MAP OF SOUTHEASTERN IOWA
Datum, base of Haight Creek Member, Burlington Limestone
Mary C. Parker
1961
Legend
Kinderhook-Osage boundary
Well location
Contour interval 50 feet
Reference is mean sea level
Scale
0 5 10 15 20 miles
Ames-Roland anticline
Oquawka anticline
Sperry anticline
Burlington anticline
Skunk River anticline
Bentonsport anticline
Lincoln Fold
Ames
Marshalltown
Grinnell
Des Moines
Oskaloosa
Ottumwa
Washington
Mt. Pleasant
Burlington
Ft. Madison
Keokuk
Centerville
R. 25 W.
R. 20 W.
R. 15 W.
R. 10 W.
R. 5 W.
R. 1 W.
T. 85 N.
T. 80 N.
T. 75 N.
T. 70 N.
T. 65 N.

DISTRIBUTION OF DOLBEE CREEK MEMBER AND THICKNESS MAP OF BURLINGTON LIMESTONE IN SOUTHEASTERN IOWA

Mary C. Parker

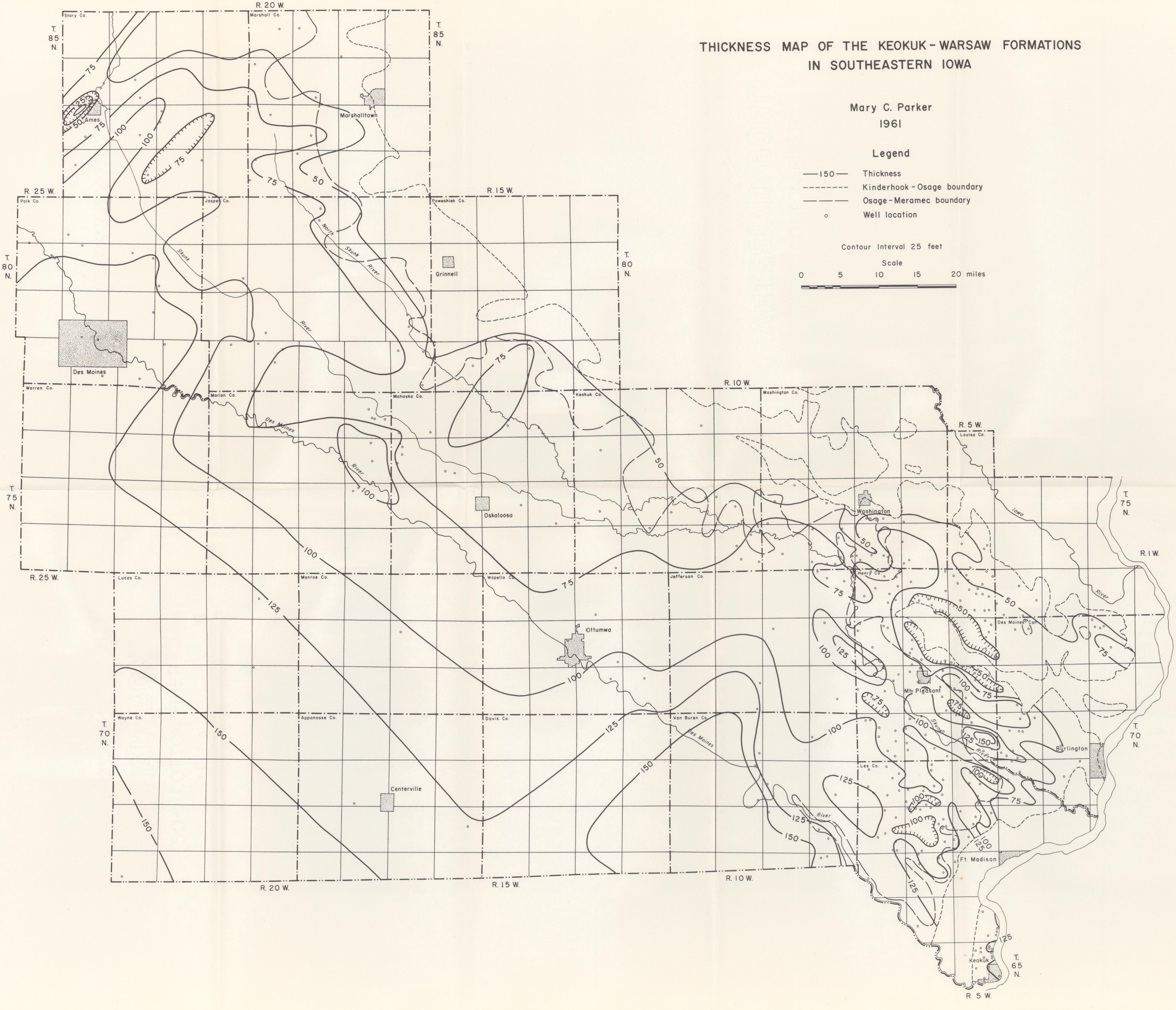
1961



THICKNESS MAP OF THE KEOKUK-WARSAW FORMATIONS IN SOUTHEASTERN IOWA

Mary C. Parker

1961



LITHOFACIES MAP OF THE KEOKUK-WARSAW FORMATIONS IN SOUTHEASTERN IOWA

Stanley E. Harris, Jr.

1961